US012239320B2

(12) **United States Patent**
**Yates et al.**

(10) **Patent No.: US 12,239,320 B2**
(45) **Date of Patent: *Mar. 4, 2025**

(54) **METHOD OF USING REINFORCED FLEXIBLE CIRCUITS WITH MULTIPLE SENSORS TO OPTIMIZE PERFORMANCE OF RADIO FREQUENCY DEVICES**

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( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **18/378,520**

(22) Filed: **Oct. 10, 2023**

(65) **Prior Publication Data**

US 2024/0032918 A1 Feb. 1, 2024

**Related U.S. Application Data**

(63) Continuation of application No. 17/825,754, filed on May 26, 2022, now Pat. No. 11,779,337, which is a (Continued)

(51) **Int. Cl.**
***A61B 17/072*** (2006.01)
***A61B 1/00*** (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC .... ***A61B 17/07207*** (2013.01); ***A61B 1/00009*** (2013.01); ***A61B 1/000096*** (2022.02);
(Continued)

(58) **Field of Classification Search**
CPC ..... A61B 34/20; A61B 34/32; A61B 34/71; A61B 90/35; A61B 90/361;
(Continued)

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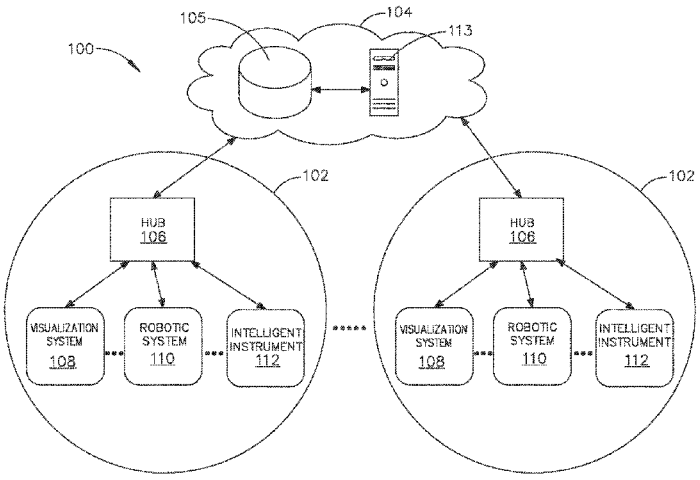
(57) **ABSTRACT**

A method implemented by a surgical instrument is disclosed. The surgical instrument includes first and second jaws and a flexible circuit including multiple sensors to optimize performance of a radio frequency (RF) device. The flexible circuit includes at least one therapeutic electrode couplable to a source of RF energy, at least two sensing electrodes, and at least one insulative layer. The insulative layer is positioned between the at least one therapeutic electrode and the at least two sensing electrodes. The method includes contacting tissue positioned between the first and second jaws of the surgical instrument with the at least one therapeutic electrode and at the least two sensing electrodes; sensing signals from the at least two sensing electrodes; and controlling RF energy delivered to the at least one therapeutic electrode based on the sensed signals.

**20 Claims, 43 Drawing Sheets**



**Related U.S. Application Data**

continuation of application No. 16/209,427, filed on Dec. 4, 2018, now Pat. No. 11,389,164.

(60) Provisional application No. 62/773,742, filed on Nov. 30, 2018, provisional application No. 62/773,728, filed on Nov. 30, 2018, provisional application No. 62/773,741, filed on Nov. 30, 2018, provisional application No. 62/773,778, filed on Nov. 30, 2018, provisional application No. 62/750,529, filed on Oct. 25, 2018, provisional application No. 62/750,539, filed on Oct. 25, 2018, provisional application No. 62/750,555, filed on Oct. 25, 2018, provisional application No. 62/729,191, filed on Sep. 10, 2018, provisional application No. 62/729,184, filed on Sep. 10, 2018, provisional application No. 62/729,195, filed on Sep. 10, 2018, provisional application No. 62/729,182, filed on Sep. 10, 2018, provisional application No. 62/729,176, filed on Sep. 10, 2018, provisional application No. 62/729,186, filed on Sep. 10, 2018, provisional application No. 62/729,177, filed on Sep. 10, 2018, provisional application No. 62/729,185, filed on Sep. 10, 2018, provisional application No. 62/729,183, filed on Sep. 10, 2018, provisional application No. 62/721,999, filed on Aug. 23, 2018, provisional application No. 62/721,995, filed on Aug. 23, 2018, provisional application No. 62/721,994, filed on Aug. 23, 2018, provisional application No. 62/721,996, filed on Aug. 23, 2018, provisional application No. 62/721,998, filed on Aug. 23, 2018, provisional application No. 62/692,748, filed on Jun. 30, 2018, provisional application No. 62/692,768, filed on Jun. 30, 2018, provisional application No. 62/692,747, filed on Jun. 30, 2018, provisional application No. 62/691,257, filed on Jun. 28, 2018, provisional application No. 62/691,230, filed on Jun. 28, 2018, provisional application No. 62/691,228, filed on Jun. 28, 2018, provisional application No. 62/691,251, filed on Jun. 28, 2018, provisional application No. 62/691,219, filed on Jun. 28, 2018, provisional application No. 62/691,262, filed on Jun. 28, 2018, provisional application No. 62/691,227, filed on Jun. 28, 2018, provisional application No. 62/665,139, filed on May 1, 2018, provisional application No. 62/665,134, filed on May 1, 2018, provisional application No. 62/665,192, filed on May 1, 2018, provisional application No. 62/665,177, filed on May 1, 2018, provisional application No. 62/665,128, filed on May 1, 2018, provisional application No. 62/665,129, filed on May 1, 2018, provisional application No. 62/659,900, filed on Apr. 19, 2018, provisional application No. 62/650,898, filed on Mar. 30, 2018, provisional application No. 62/650,882, filed on Mar. 30, 2018, provisional application No. 62/650,887, filed on Mar. 30, 2018, provisional application No. 62/650,877, filed on Mar. 30, 2018, provisional application No. 62/649,315, filed on Mar. 28, 2018, provisional application No. 62/649,323, filed on Mar. 28, 2018, provisional application No. 62/649,302, filed on Mar. 28, 2018, provisional application No. 62/649,313, filed on Mar. 28, 2018, provisional application No. 62/649,310, filed on Mar. 28, 2018, provisional application No. 62/649,333, filed on Mar. 28, 2018, provisional application No. 62/649,320, filed on Mar. 28, 2018, provisional application No. 62/649,296, filed on Mar. 28, 2018, provisional application No. 62/649,291, filed on Mar. 28, 2018, provisional application No. 62/649,327, filed on Mar. 28, 2018, provisional application No. 62/649,300, filed on Mar. 28, 2018, provisional application No. 62/649,294, filed on Mar. 28, 2018, provisional application No. 62/649,307, filed on Mar. 28, 2018, provisional application No. 62/649,309, filed on Mar. 28, 2018, provisional application No. 62/611,339, filed on Dec. 28, 2017, provisional application No. 62/611,340, filed on Dec. 28, 2017, provisional application No. 62/611,341, filed on Dec. 28, 2017.

(51) **Int. Cl.**

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| ***A61B 1/05*** | (2006.01) |
| ***A61B 1/06*** | (2006.01) |
| ***A61B 5/00*** | (2006.01) |
| ***A61B 5/026*** | (2006.01) |
| ***A61B 6/00*** | (2024.01) |
| ***A61B 17/068*** | (2006.01) |
| ***A61B 17/11*** | (2006.01) |
| ***A61B 17/115*** | (2006.01) |
| ***A61B 17/128*** | (2006.01) |
| ***A61B 17/32*** | (2006.01) |
| ***A61B 18/14*** | (2006.01) |
| ***A61B 34/00*** | (2016.01) |
| ***A61B 34/20*** | (2016.01) |
| ***A61B 34/32*** | (2016.01) |
| ***A61B 90/00*** | (2016.01) |
| ***A61B 90/35*** | (2016.01) |
| ***A61M 1/00*** | (2006.01) |
| ***B25J 9/16*** | (2006.01) |
| ***B25J 13/00*** | (2006.01) |
| ***G06K 7/10*** | (2006.01) |
| ***G06K 19/077*** | (2006.01) |
| ***G16H 10/60*** | (2018.01) |
| ***G16H 40/63*** | (2018.01) |
| ***G16H 40/67*** | (2018.01) |
| ***G16H 50/20*** | (2018.01) |
| ***G16H 70/20*** | (2018.01) |
| ***H01Q 1/22*** | (2006.01) |
| ***H04L 9/40*** | (2022.01) |
| ***H04L 67/10*** | (2022.01) |
| ***H04L 67/12*** | (2022.01) |
| ***H04N 5/272*** | (2006.01) |
| ***H04N 7/18*** | (2006.01) |
| ***H05K 1/02*** | (2006.01) |
| ***H05K 1/18*** | (2006.01) |
| *A61B 17/00* | (2006.01) |
| *A61B 18/00* | (2006.01) |
| *A61B 34/30* | (2016.01) |
| *A61B 90/30* | (2016.01) |
| *A61M 13/00* | (2006.01) |

(52) **U.S. Cl.**

CPC ..... ***A61B 1/00045*** (2013.01); ***A61B 1/051*** (2013.01); ***A61B 1/0661*** (2013.01); ***A61B 5/0066*** (2013.01); ***A61B 5/0075*** (2013.01); ***A61B 5/0261*** (2013.01); ***A61B 6/5247*** (2013.01); ***A61B 17/0682*** (2013.01); ***A61B 17/072*** (2013.01); ***A61B 17/1114*** (2013.01); ***A61B 17/1155*** (2013.01); ***A61B 17/1285*** (2013.01); ***A61B 17/320092*** (2013.01); ***A61B 18/1442*** (2013.01); ***A61B 18/1445*** (2013.01); ***A61B 34/20*** (2016.02); ***A61B 34/32*** (2016.02);

***A61B 34/71*** (2016.02); ***A61B 90/35*** (2016.02); ***A61B 90/361*** (2016.02); ***A61M 1/73*** (2021.05); ***A61M 1/79*** (2021.05); ***B25J 9/1697*** (2013.01); ***B25J 13/006*** (2013.01); ***G06K 7/10316*** (2013.01); ***G06K 19/07749*** (2013.01); ***G16H 10/60*** (2018.01); ***G16H 40/63*** (2018.01); ***G16H 40/67*** (2018.01); ***G16H 50/20*** (2018.01); ***G16H 70/20*** (2018.01); ***H01Q 1/22*** (2013.01); ***H04L 63/1416*** (2013.01); ***H04L 67/10*** (2013.01); ***H04L 67/12*** (2013.01); ***H04N 5/272*** (2013.01); ***H04N 7/183*** (2013.01); ***H05K 1/028*** (2013.01); ***H05K 1/189*** (2013.01); *A61B 2017/00022* (2013.01); *A61B 2017/00026* (2013.01); *A61B 2017/0003* (2013.01); *A61B 2017/00039* (2013.01); *A61B 2017/00044* (2013.01); *A61B 2017/00057* (2013.01); *A61B 2017/00061* (2013.01); *A61B 2017/00075* (2013.01); *A61B 2017/00084* (2013.01); *A61B 2017/00097* (2013.01); *A61B 2017/00106* (2013.01); *A61B 2017/0011* (2013.01); *A61B 2017/00115* (2013.01); *A61B 2017/00119* (2013.01); *A61B 2017/00199* (2013.01); *A61B 2017/00203* (2013.01); *A61B 2017/00221* (2013.01); *A61B 2017/00398* (2013.01); *A61B 2017/00402* (2013.01); *A61B 2017/00734* (2013.01); *A61B 2017/00809* (2013.01); *A61B 2017/00818* (2013.01); *A61B 2017/07257* (2013.01); *A61B 2017/07271* (2013.01); *A61B 2017/07278* (2013.01); *A61B 2017/07285* (2013.01); *A61B 2017/1132* (2013.01); *A61B 2017/32007* (2017.08); *A61B 2017/320074* (2017.08); *A61B 2017/320084* (2013.01); *A61B 2017/320095* (2017.08); *A61B 2017/320097* (2017.08); *A61B 2018/00541* (2013.01); *A61B 2018/00589* (2013.01); *A61B 2018/00595* (2013.01); *A61B 2018/00601* (2013.01); *A61B 2018/00607* (2013.01); *A61B 2018/0063* (2013.01); *A61B 2018/00642* (2013.01); *A61B 2018/00684* (2013.01); *A61B 2018/00791* (2013.01); *A61B 2018/00827* (2013.01); *A61B 2018/00875* (2013.01); *A61B 2018/00892* (2013.01); *A61B 2018/00988* (2013.01); *A61B 2018/00994* (2013.01); *A61B 2034/2055* (2016.02); *A61B 2034/2057* (2016.02); *A61B 34/30* (2016.02); *A61B 2034/301* (2016.02); *A61B 2034/305* (2016.02); *A61B 2090/309* (2016.02); *A61B 2217/005* (2013.01); *A61B 2217/007* (2013.01); *A61B 2218/002* (2013.01); *A61B 2218/007* (2013.01); *A61B 2218/008* (2013.01); *A61M 1/80* (2021.05); *A61M 13/003* (2013.01); *A61M 2205/3306* (2013.01); *A61M 2205/3327* (2013.01); *A61M 2205/3331* (2013.01); *A61M 2205/3365* (2013.01); *A61M 2205/3368* (2013.01); *G05B 2219/40174* (2013.01); *G05B 2219/45119* (2013.01)

(58) **Field of Classification Search**

CPC ..... A61B 1/000096; A61B 1/00009; A61B 1/00045; A61B 1/051; A61B 1/0661; A61B 5/0066; A61B 5/0075; A61B 5/0261; A61B 6/5247; A61B 17/0682; A61B 17/072; A61B 17/1114; A61B 17/1155; A61B 17/1285; A61B 17/320092; A61B 18/1442; A61B 18/1485; G16H 10/60; G16H 50/20; G16H 40/63; G16H 70/20; A61M 1/79; A61M 1/73; B25J 9/1697; G06K 19/07749; G06K 7/10316; H04L 63/1416; H04L 67/10

USPC ..... 606/41, 32, 34, 51, 207

See application file for complete search history.

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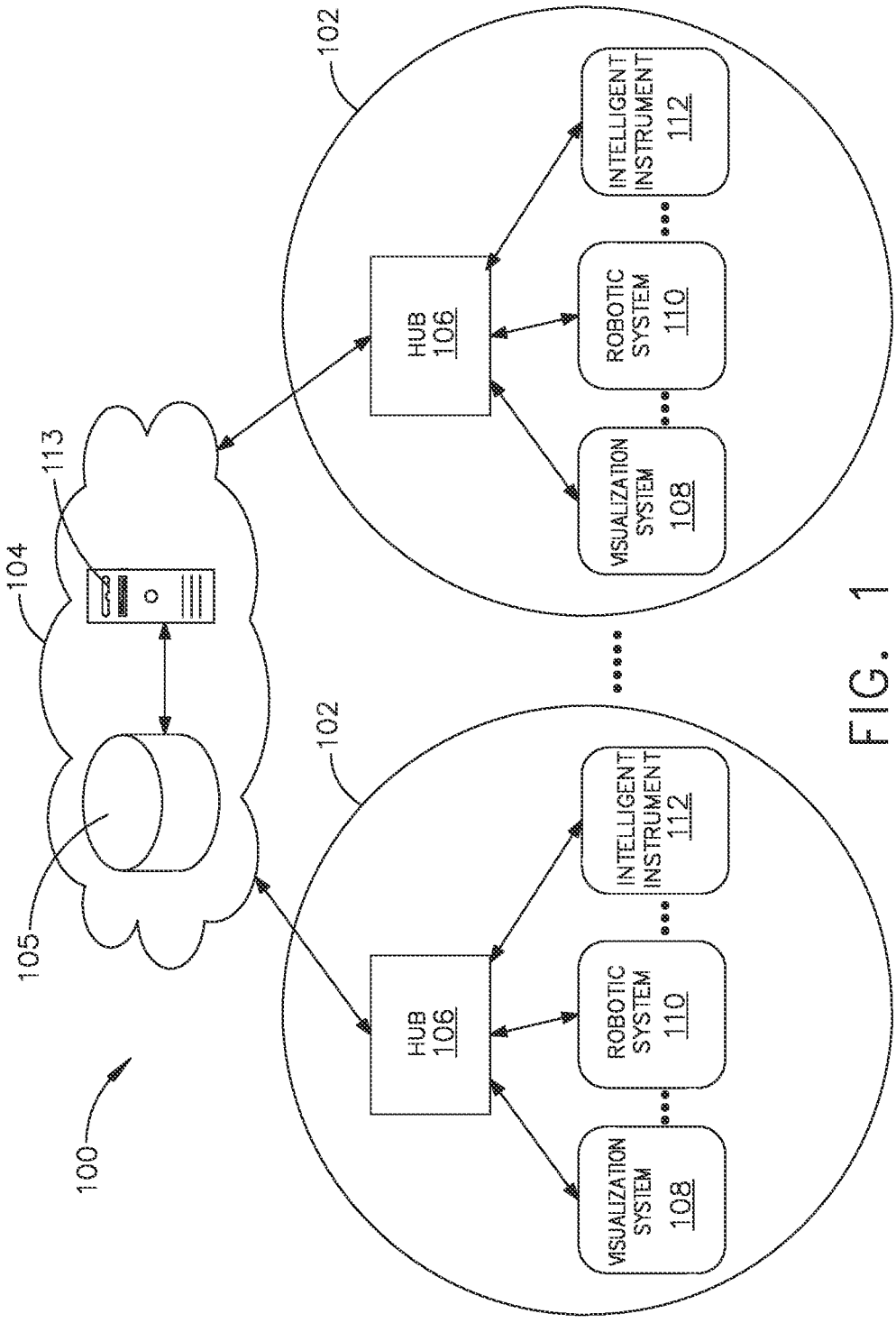
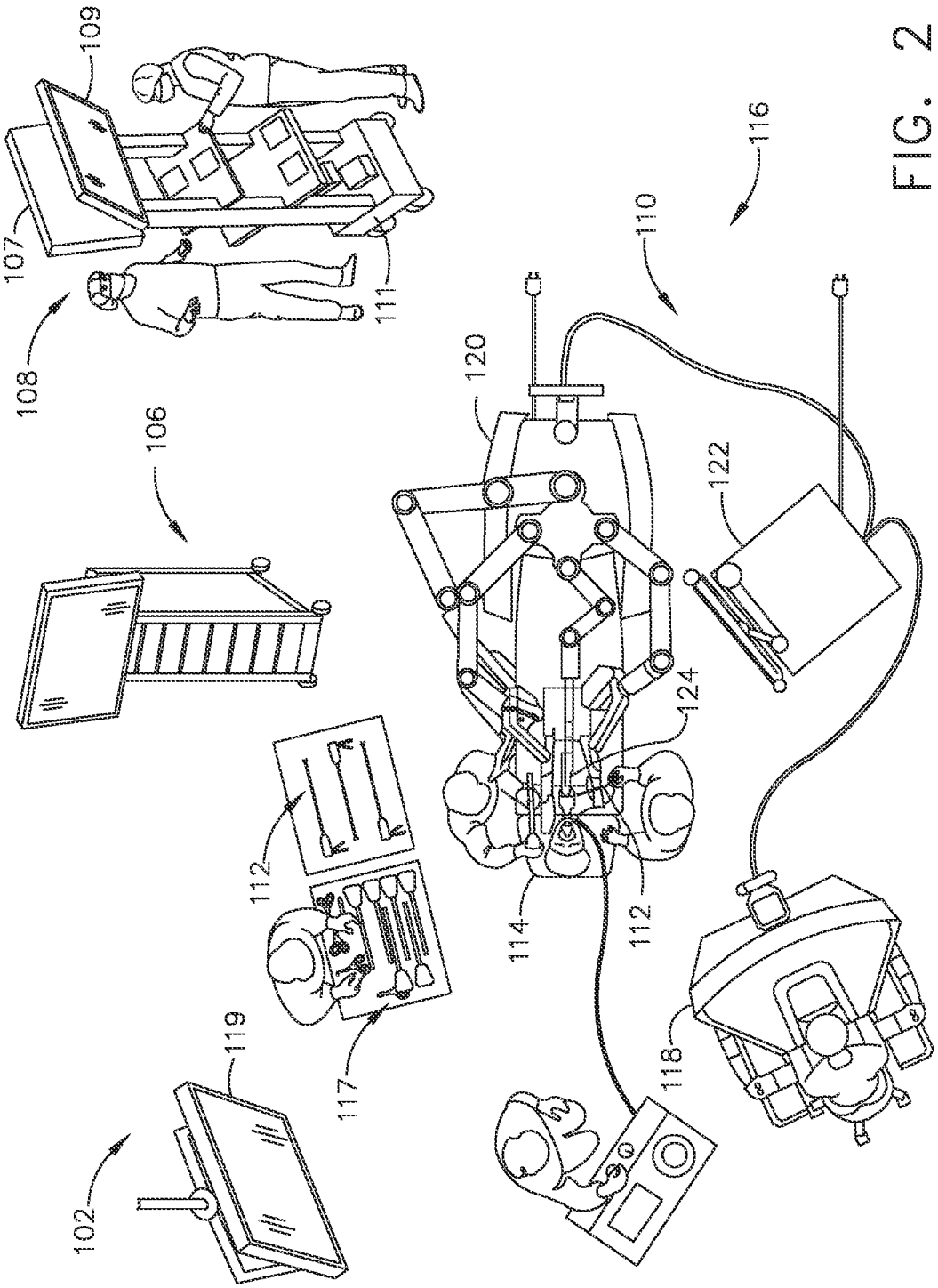

100
102
HUB 106
VISUALIZATION SYSTEM 108
ROBOTIC SYSTEM 110
INTELLIGENT INSTRUMENT 112
104
105
113

FIG. 1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107
108
111
116
110
120
106
122
124
112
114
112
119
117
118
102

FIG. 2

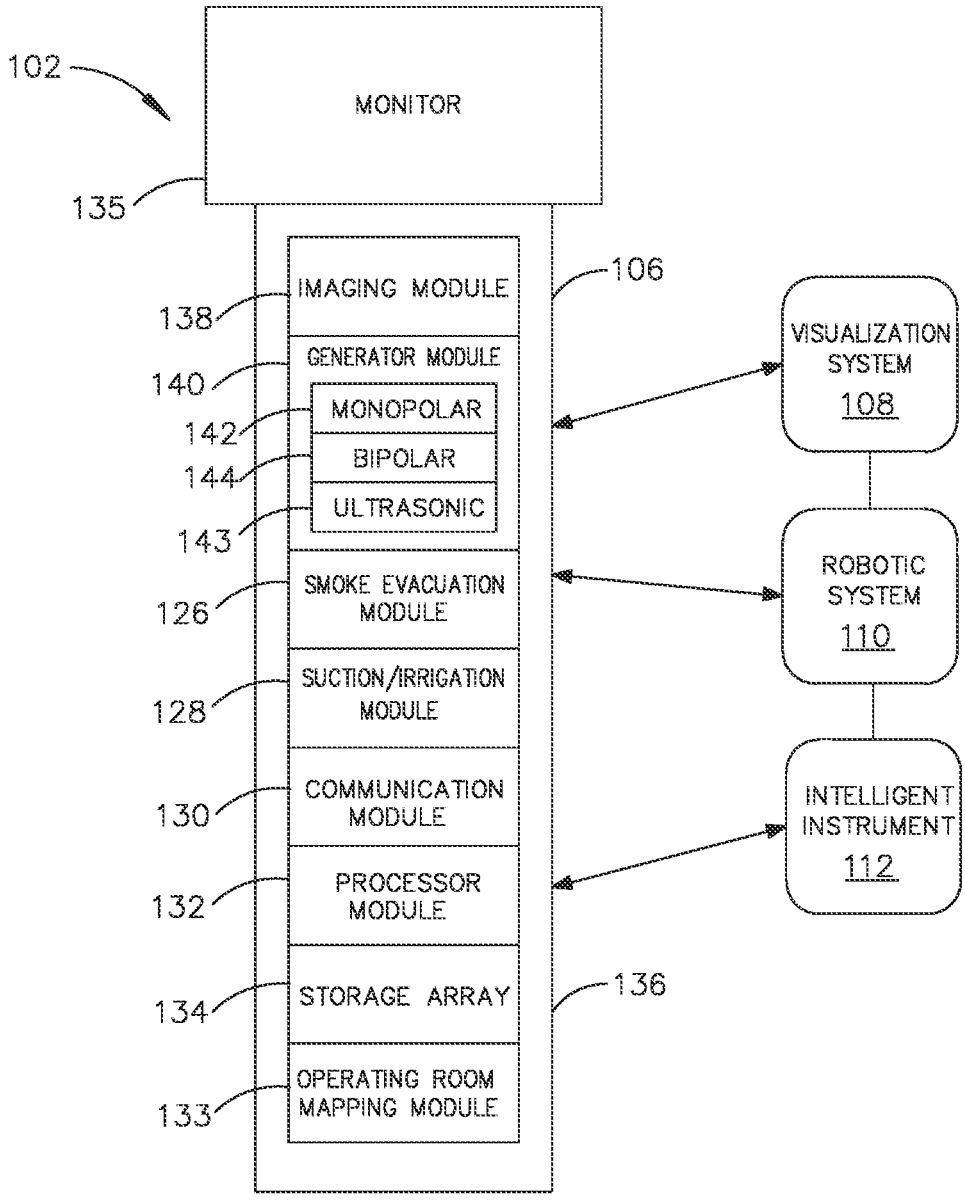
102
MONITOR
135
106
IMAGING MODULE
138
GENERATOR MODULE
140
MONOPOLAR
142
BIPOLAR
144
ULTRASONIC
143
SMOKE EVACUATION MODULE
126
SUCTION/IRRIGATION MODULE
128
COMMUNICATION MODULE
130
PROCESSOR MODULE
132
STORAGE ARRAY
134
136
OPERATING ROOM MAPPING MODULE
133
VISUALIZATION SYSTEM
108
ROBOTIC SYSTEM
110
INTELLIGENT INSTRUMENT
112

FIG. 3

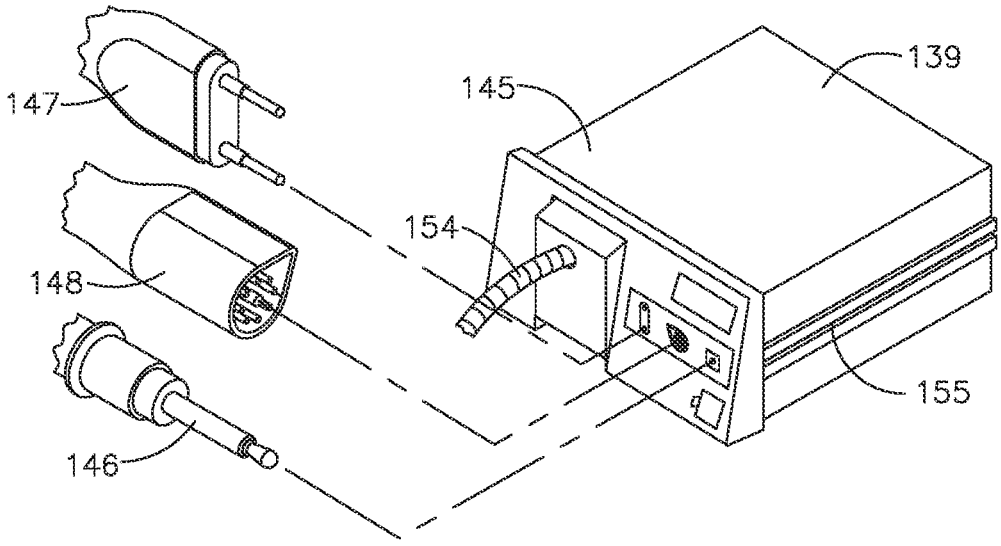
147
148
146
145
154
139
155

FIG. 5

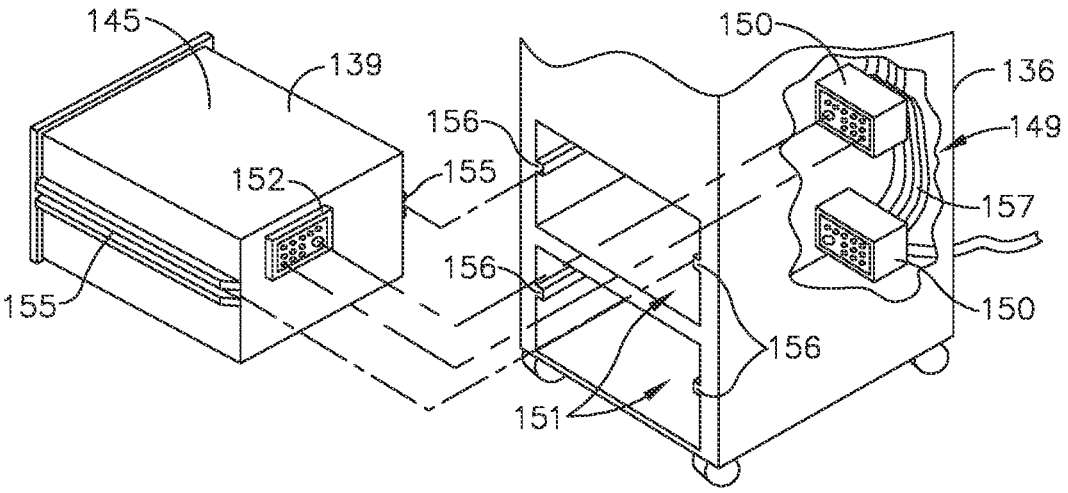
145
139
152
155
155
156
156
156
150
136
149
157
150
151

FIG. 4

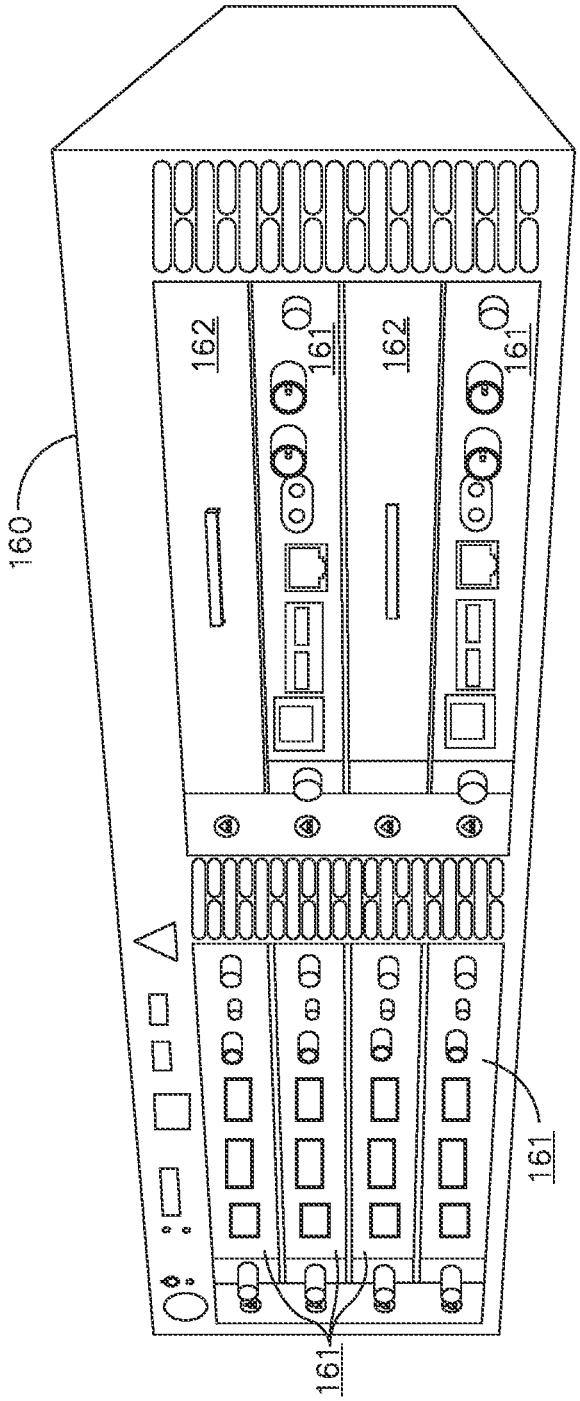


FIG. 6

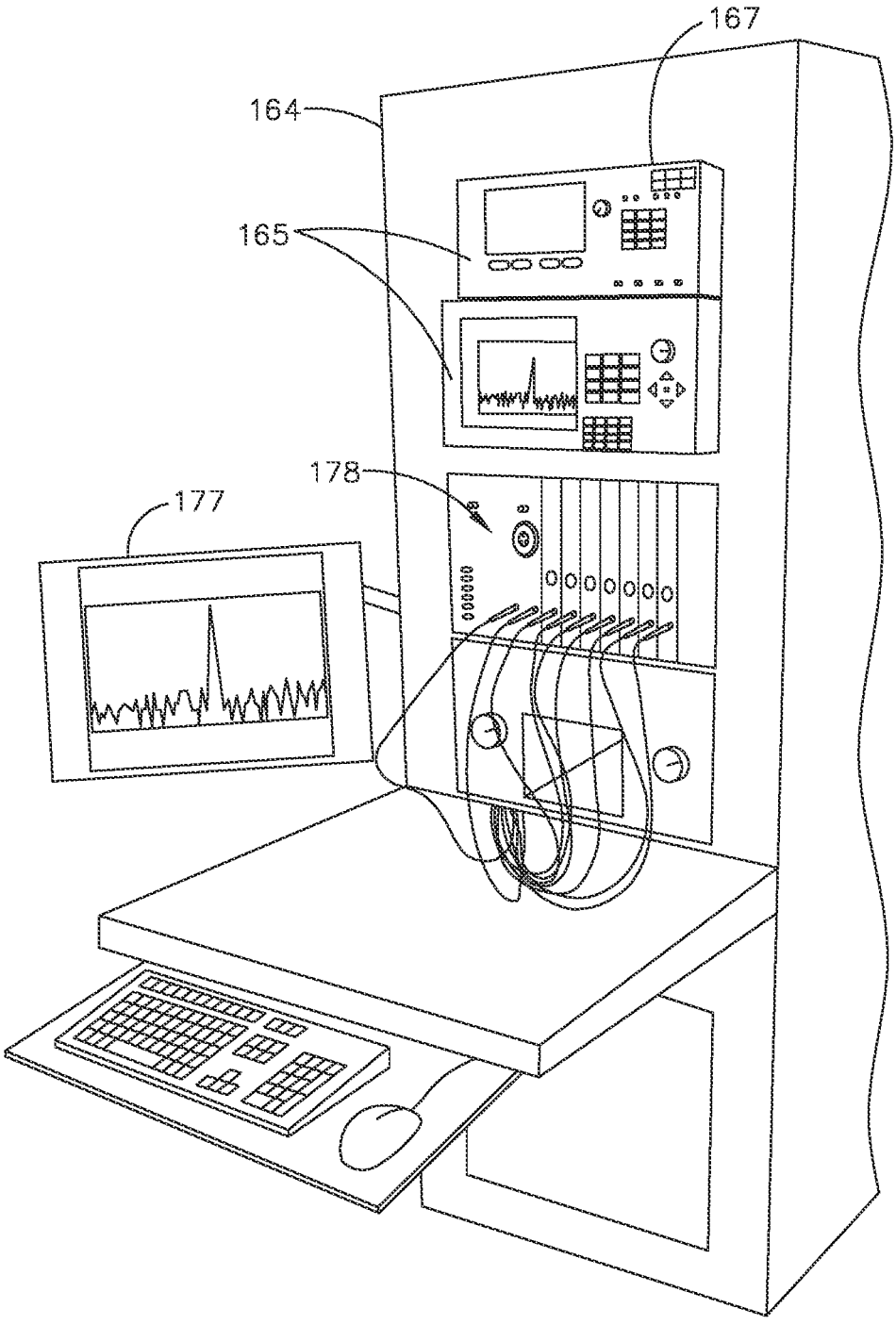


FIG. 7

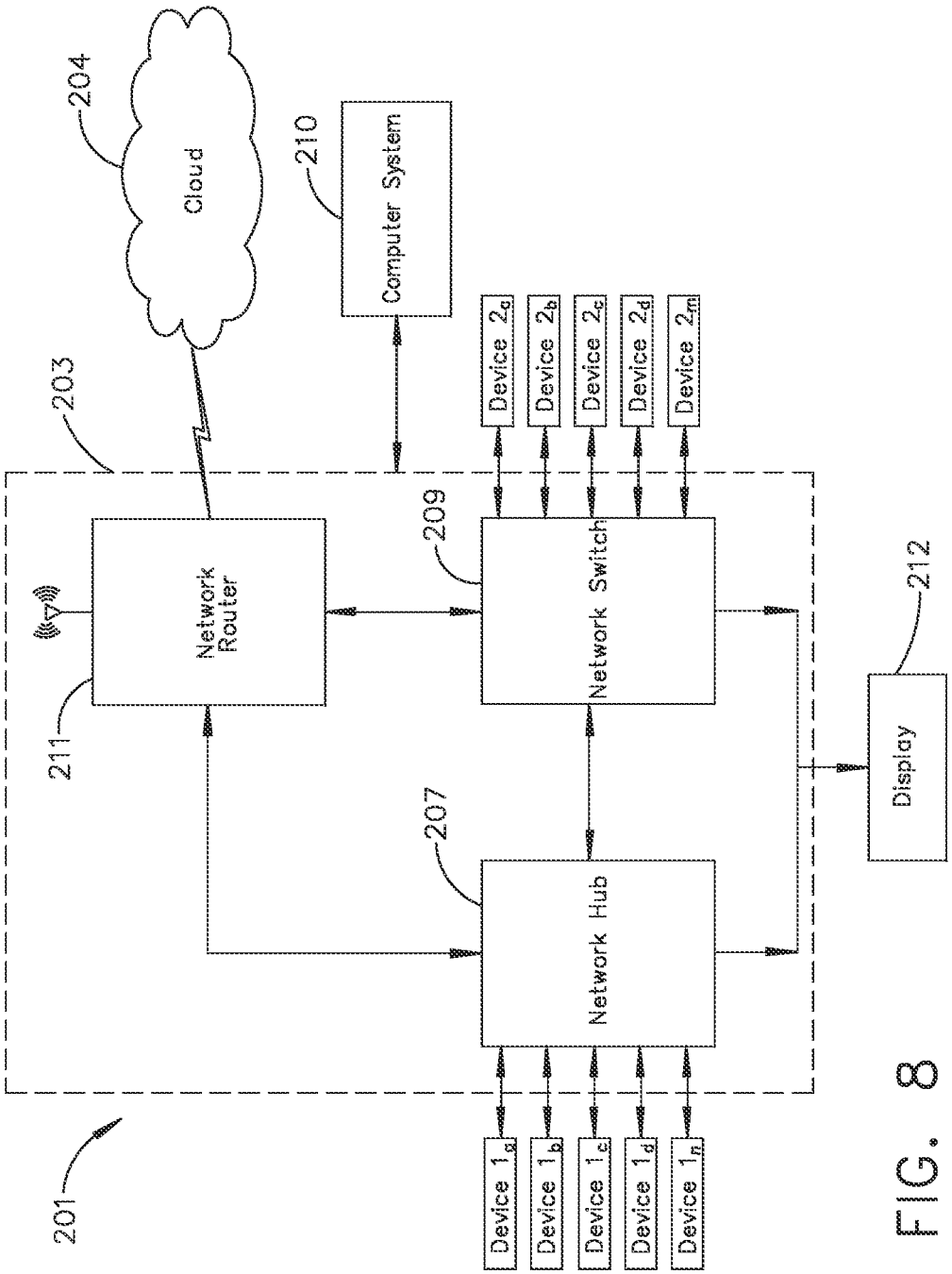
204
Cloud
210
Computer System
203
Device 2a
Device 2b
Device 2c
Device 2d
Device 2m
209
Network Switch
212
Network Router
211
Display
207
Network Hub
201
Device 1a
Device 1b
Device 1c
Device 1d
Device 1n

FIG. 8

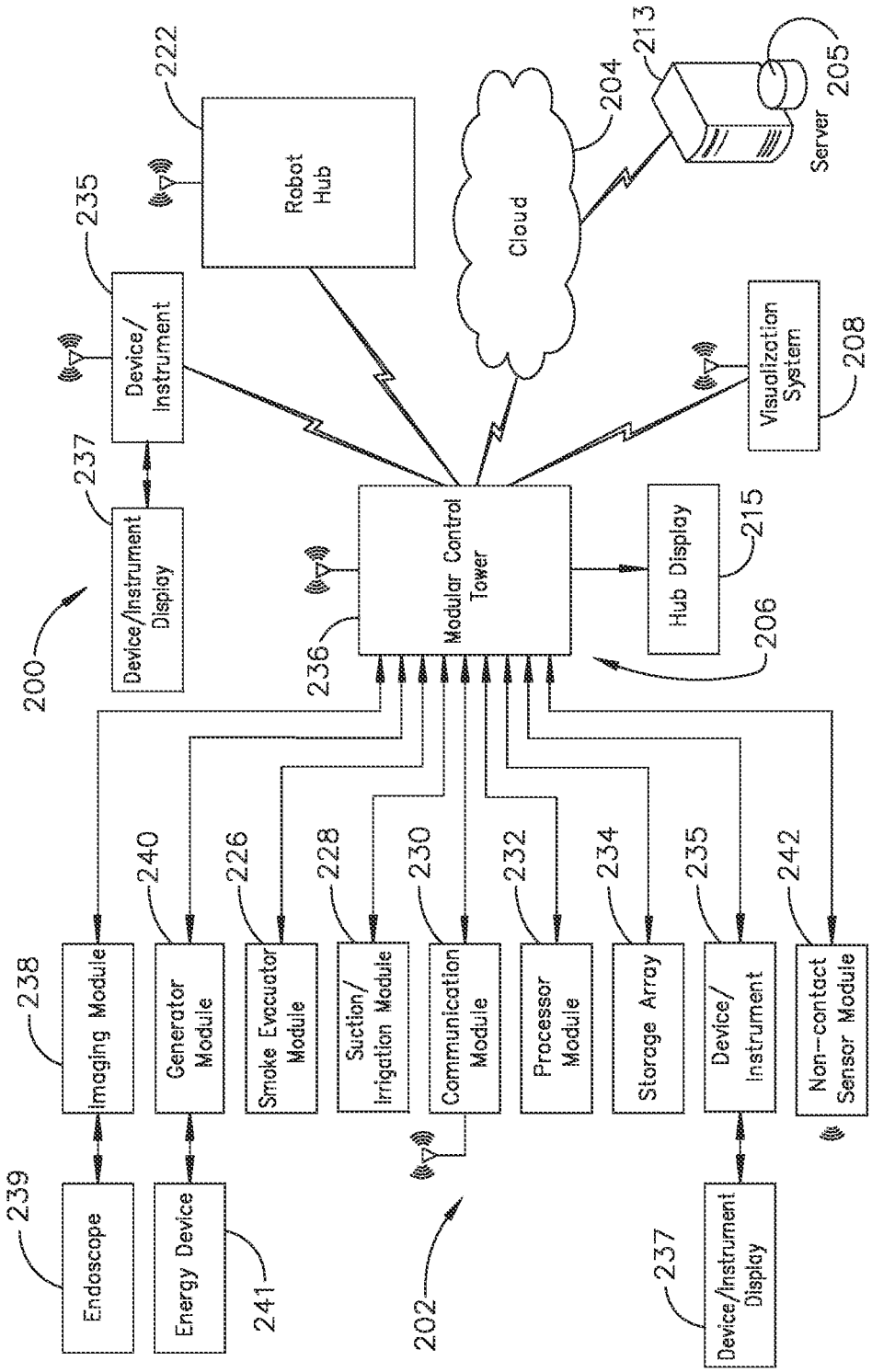
Robot Hub
222
Cloud
204
Server
205
213
Device/ Instrument
235
Visualization System
208
Device/Instrument Display
237
200
Modular Control Tower
236
Hub Display
215
206
Imaging Module
238
Generator Module
240
Smoke Evacuator Module
226
Suction/ Irrigation Module
228
Communication Module
230
Processor Module
232
Storage Array
234
Device/ Instrument
235
Non-contact Sensor Module
242
Endoscope
239
Energy Device
241
202
Device/Instrument Display
237

FIG. 9

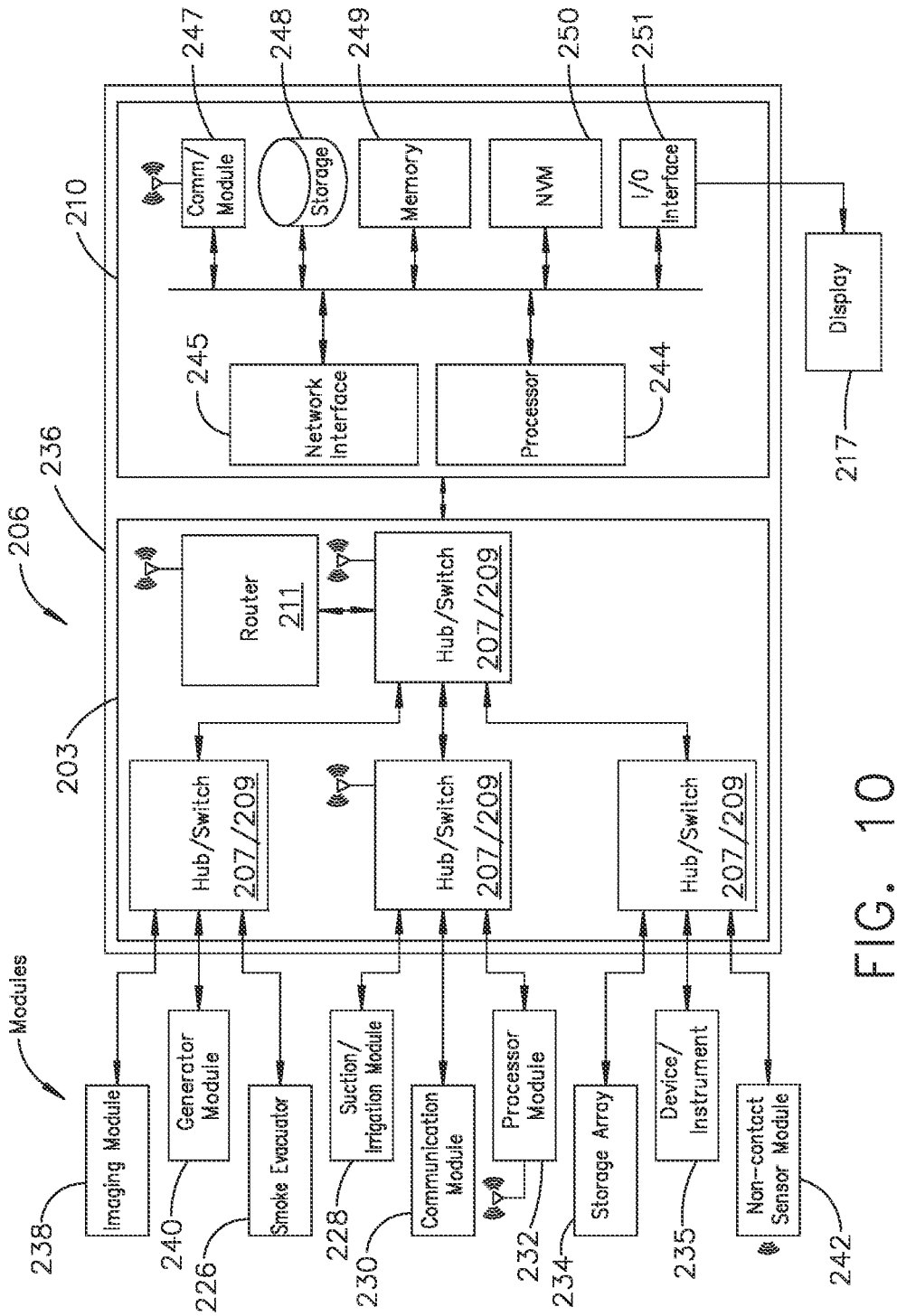
247
248
249
250
251
210
Comm/ Module
Storage
Memory
NVM
I/O Interface
Display
245
Network Interface
Processor
244
217
236
206
Router 211
Hub/Switch 207/209
203
Hub/Switch 207/209
Hub/Switch 207/209
Hub/Switch 207/209
Modules
Imaging Module
Generator Module
Smoke Evacuator
Suction/ Irrigation Module
Communication Module
Processor Module
Storage Array
Device/ Instrument
Non-contact Sensor Module
238
240
226
228
230
232
234
235
242

FIG. 10

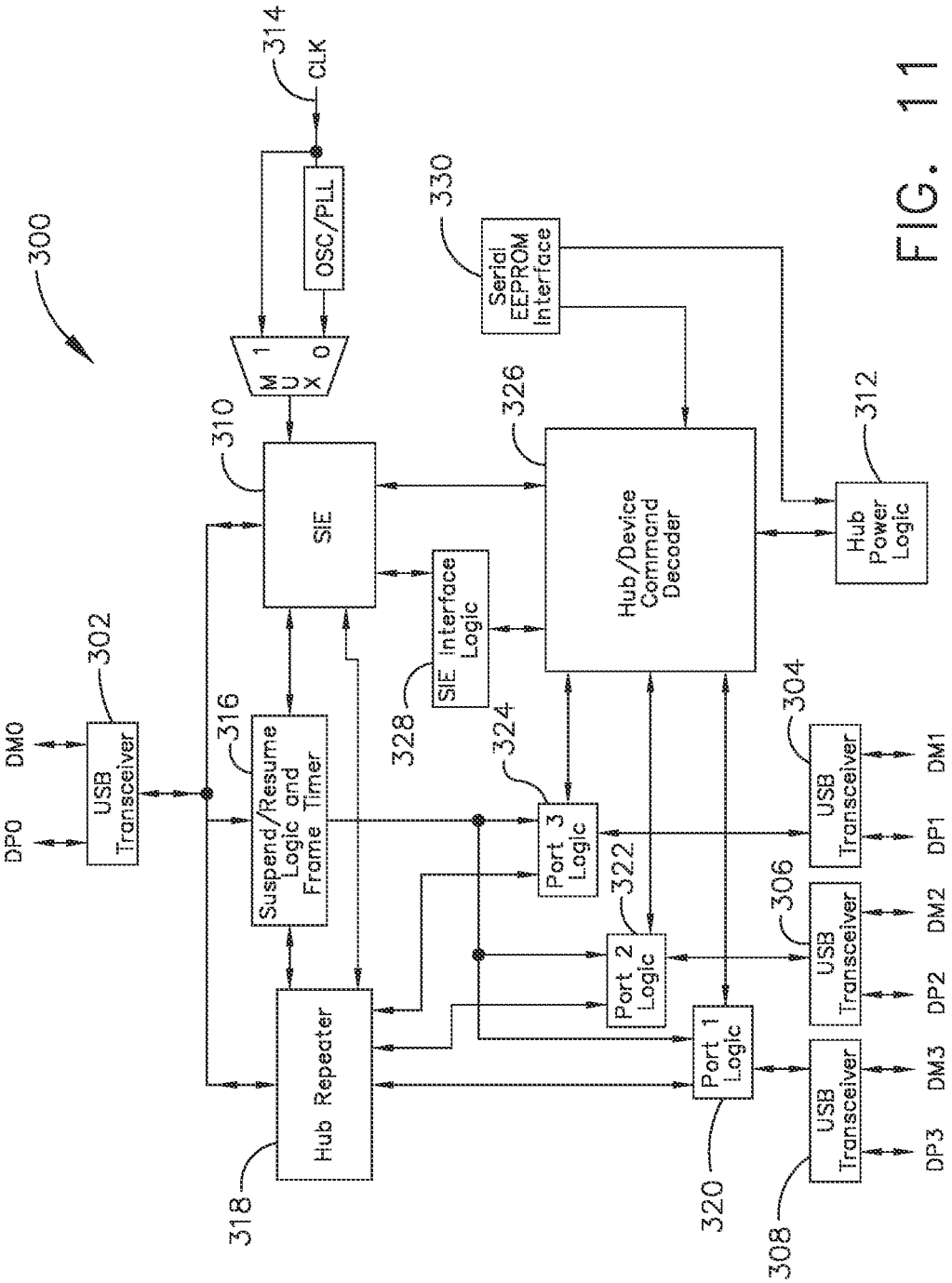
300
314
CLK
OSC/PLL
330
Serial EEPROM Interface
M U X 1 0
310
SIE
326
Hub/Device Command Decoder
312
Hub Power Logic
302
USB Transceiver
DP0
DM0
316
Suspend/Resume Logic and Frame Timer
328
SIE Interface Logic
324
Port 3 Logic
304
USB Transceiver
DP1
DM1
322
Port 2 Logic
306
USB Transceiver
DP2
DM2
Hub Repeater
318
Port 1 Logic
320
USB Transceiver
DP3
DM3
308

FIG. 11

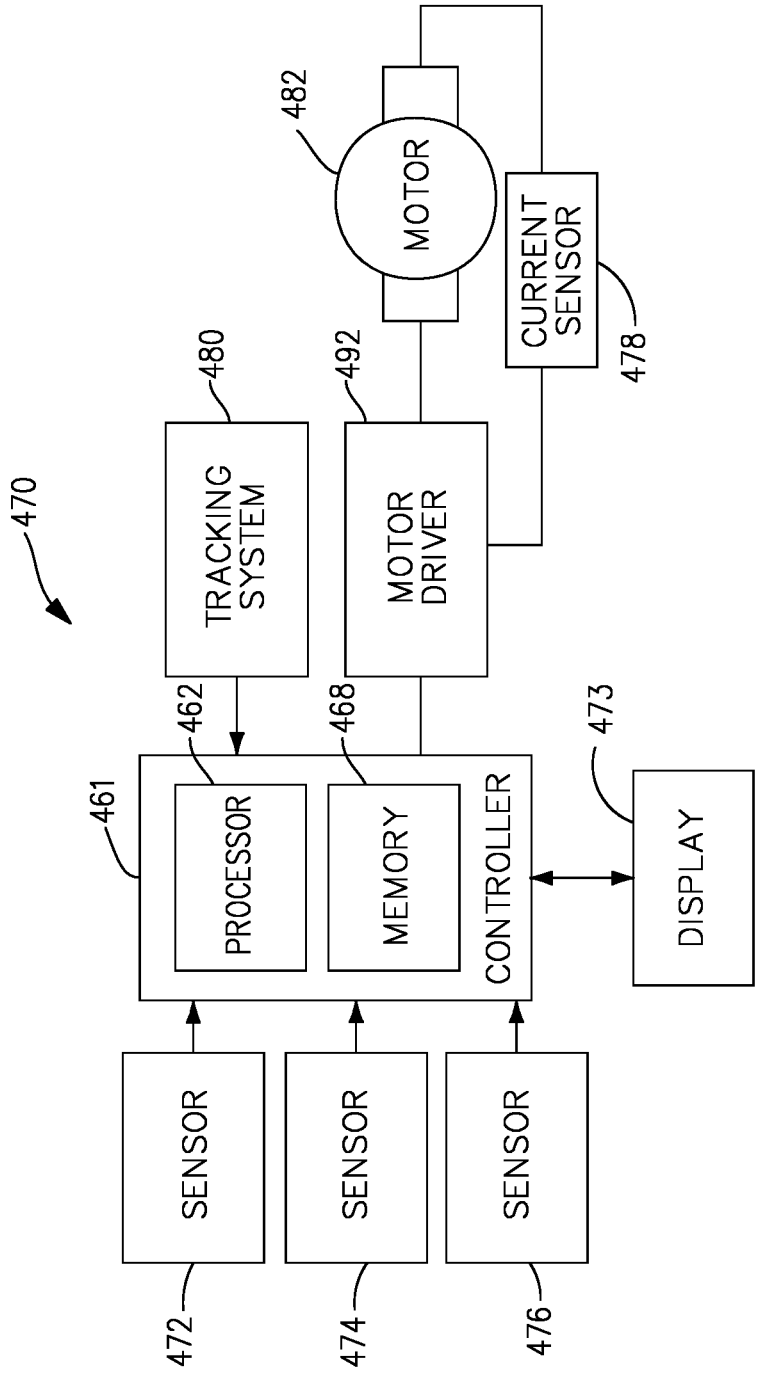
470
461
462
468
473
480
492
482
478
PROCESSOR
MEMORY
CONTROLLER
DISPLAY
TRACKING SYSTEM
MOTOR DRIVER
MOTOR
CURRENT SENSOR
SENSOR
SENSOR
SENSOR
472
474
476

FIG. 12

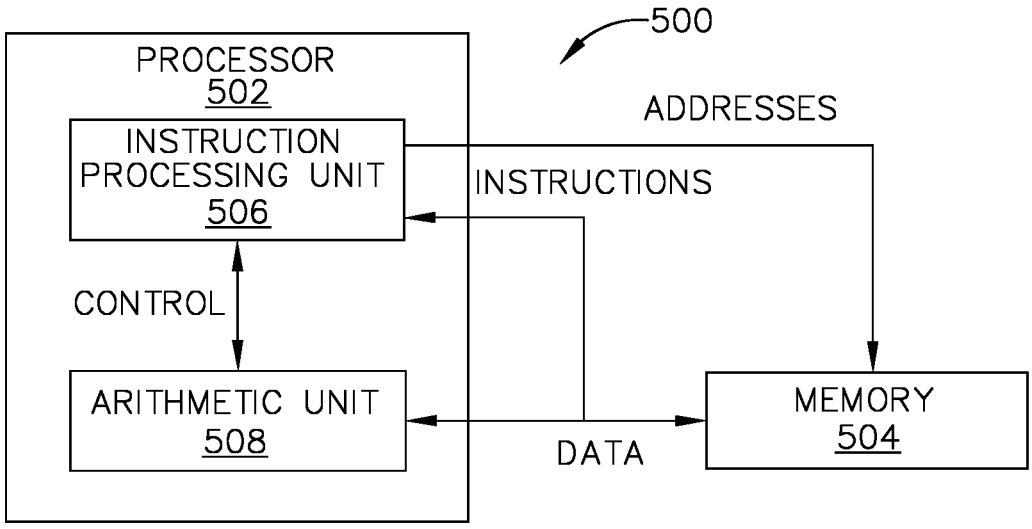


FIG. 13

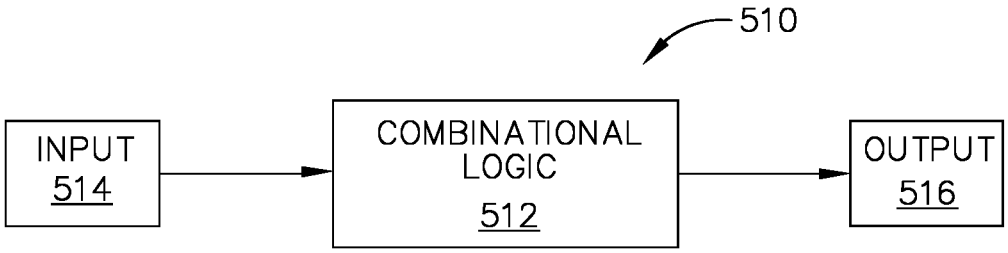


FIG. 14

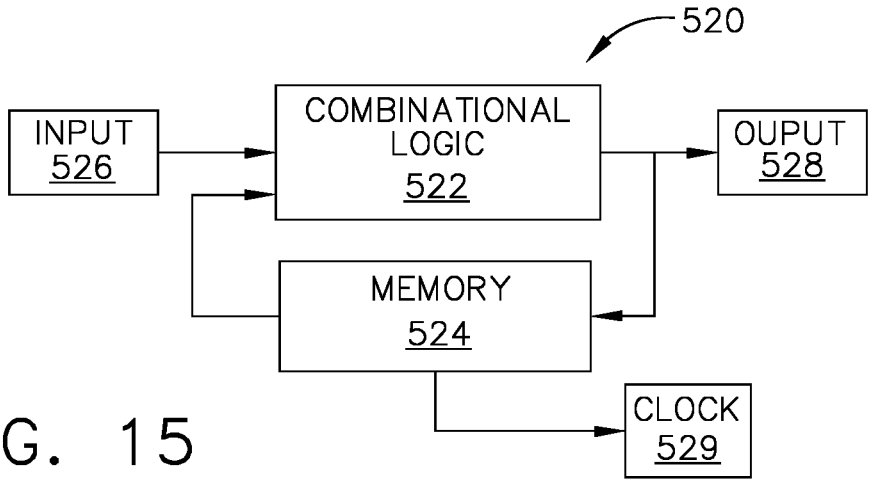


FIG. 15

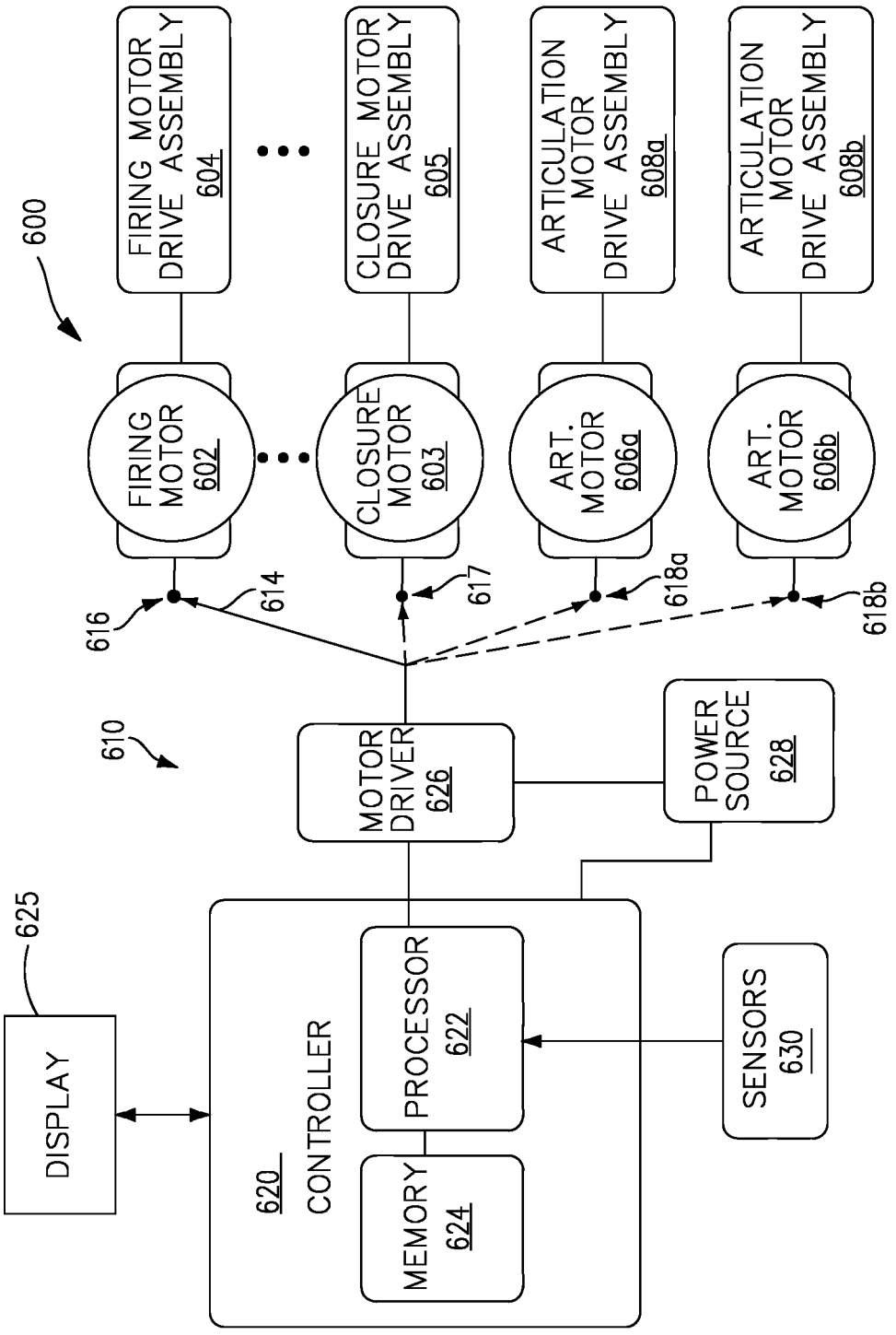
600
FIRING MOTOR DRIVE ASSEMBLY 604
CLOSURE MOTOR DRIVE ASSEMBLY 605
ARTICULATION MOTOR DRIVE ASSEMBLY 608a
ARTICULATION MOTOR DRIVE ASSEMBLY 608b
FIRING MOTOR 602
CLOSURE MOTOR 603
ART. MOTOR 606a
ART. MOTOR 606b
616
614
617
618a
618b
610
MOTOR DRIVER 626
POWER SOURCE 628
625
DISPLAY
620 CONTROLLER
PROCESSOR 622
MEMORY 624
SENSORS 630

FIG. 16

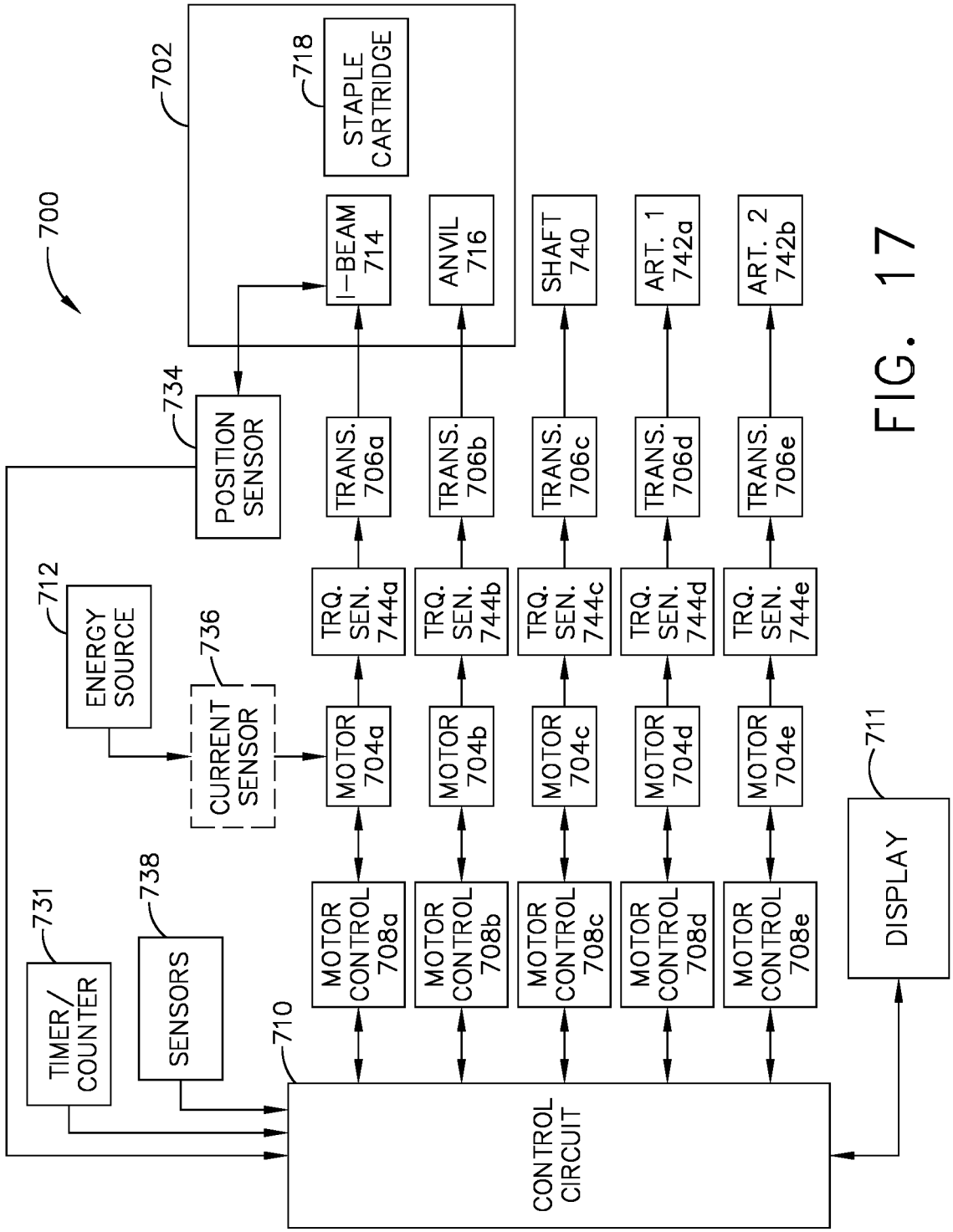
700
702
718
STAPLE CARTRIDGE
I-BEAM 714
ANVIL 716
SHAFT 740
ART. 1 742a
ART. 2 742b
734
POSITION SENSOR
TRANS. 706a
TRANS. 706b
TRANS. 706c
TRANS. 706d
TRANS. 706e
712
ENERGY SOURCE
736
CURRENT SENSOR
TRQ. SEN. 744a
TRQ. SEN. 744b
TRQ. SEN. 744c
TRQ. SEN. 744d
TRQ. SEN. 744e
MOTOR 704a
MOTOR 704b
MOTOR 704c
MOTOR 704d
MOTOR 704e
731
TIMER/ COUNTER
738
SENSORS
MOTOR CONTROL 708a
MOTOR CONTROL 708b
MOTOR CONTROL 708c
MOTOR CONTROL 708d
MOTOR CONTROL 708e
711
DISPLAY
710
CONTROL CIRCUIT

FIG. 17

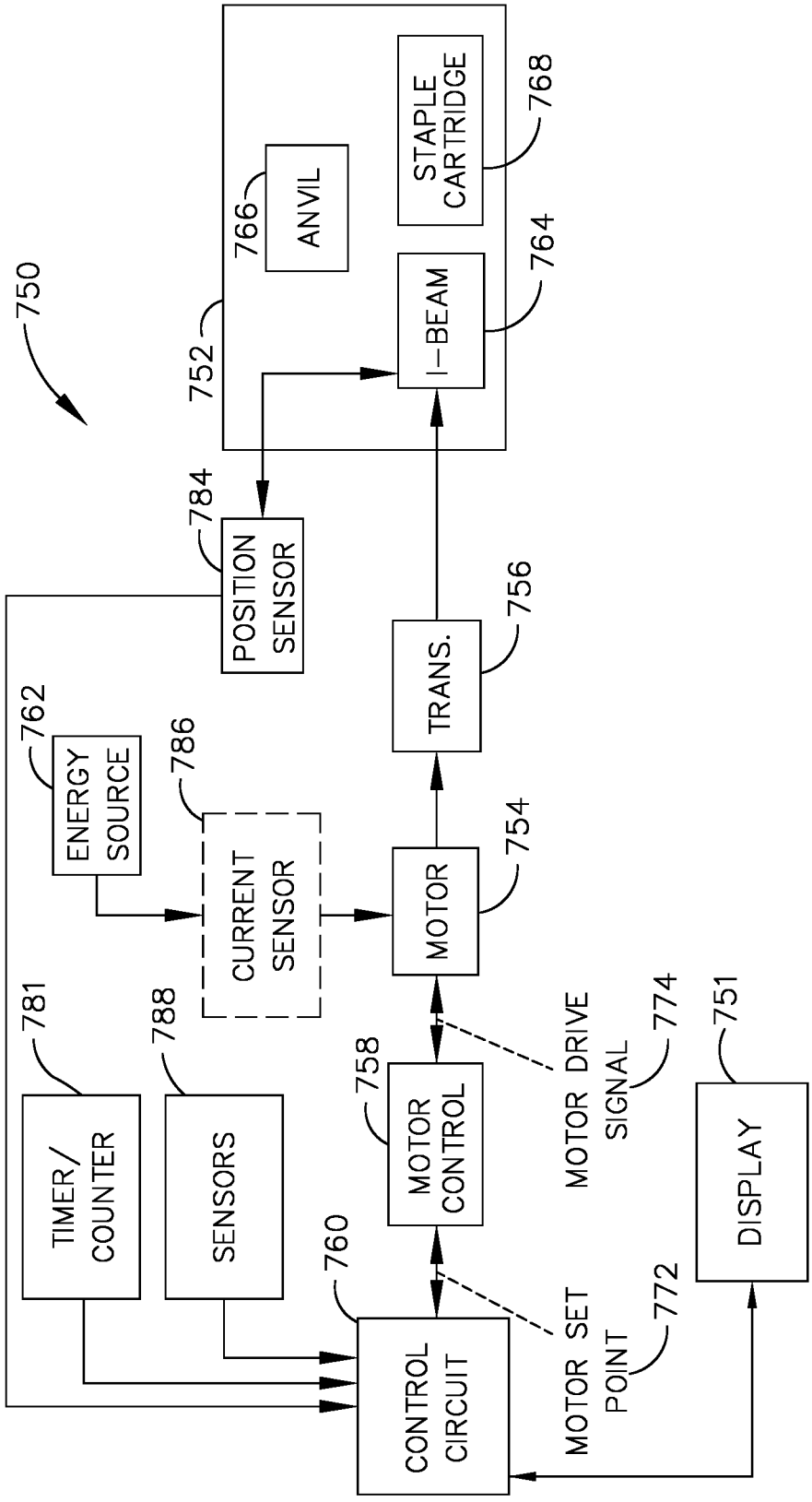
750
752
766
ANVIL
768
STAPLE CARTRIDGE
764
I-BEAM
784
POSITION SENSOR
762
ENERGY SOURCE
786
CURRENT SENSOR
756
TRANS.
754
MOTOR
781
TIMER/ COUNTER
788
SENSORS
758
MOTOR CONTROL
774
MOTOR DRIVE SIGNAL
751
DISPLAY
760
CONTROL CIRCUIT
772
MOTOR SET POINT

FIG. 18

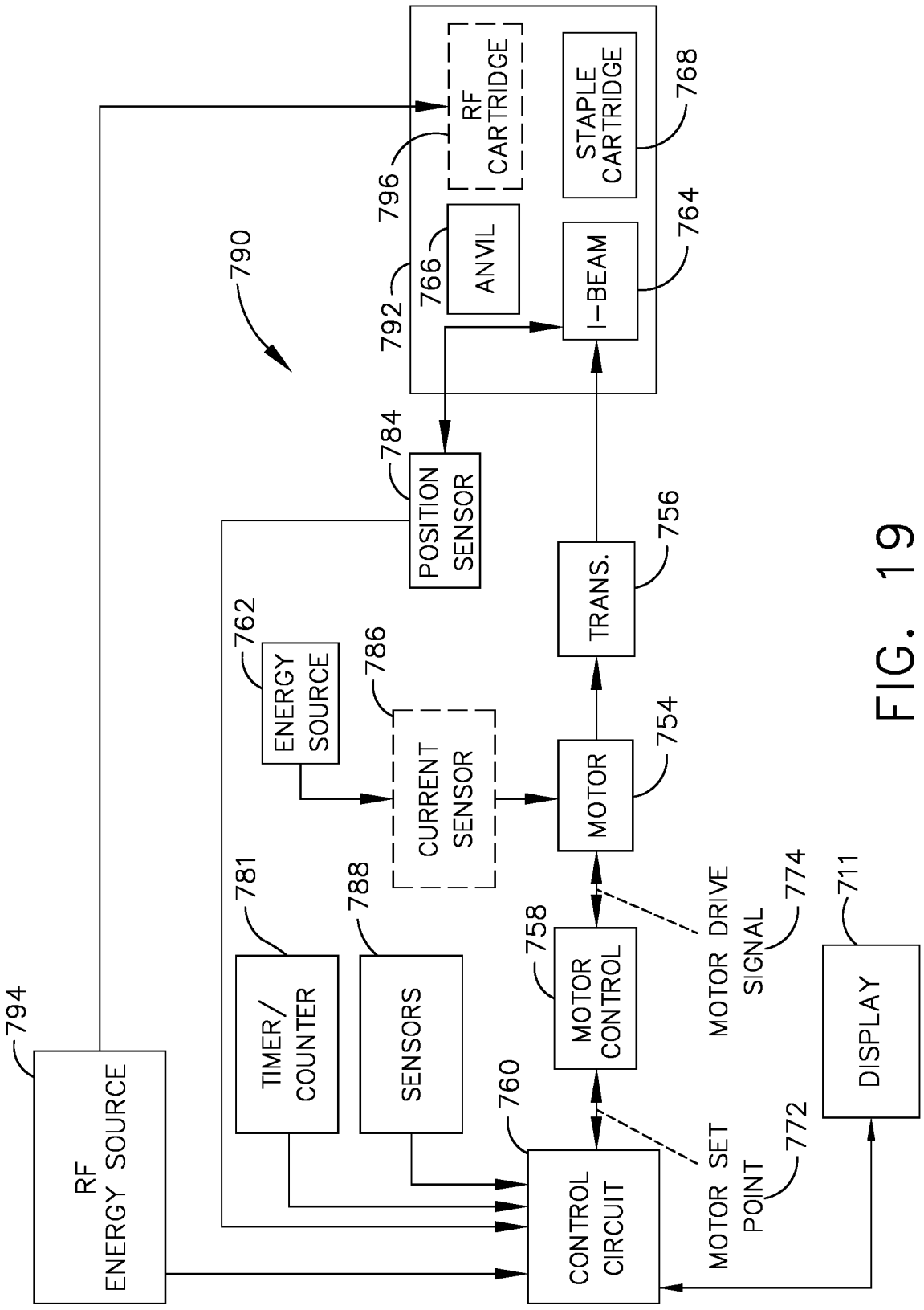
RF ENERGY SOURCE
794
TIMER/ COUNTER
781
SENSORS
788
CONTROL CIRCUIT
760
MOTOR CONTROL
758
MOTOR SET POINT
772
MOTOR DRIVE SIGNAL
774
DISPLAY
711
MOTOR
754
CURRENT SENSOR
786
ENERGY SOURCE
762
TRANS.
756
POSITION SENSOR
784
790
792
796
ANVIL
766
RF CARTRIDGE
I-BEAM
764
STAPLE CARTRIDGE
768

FIG. 19

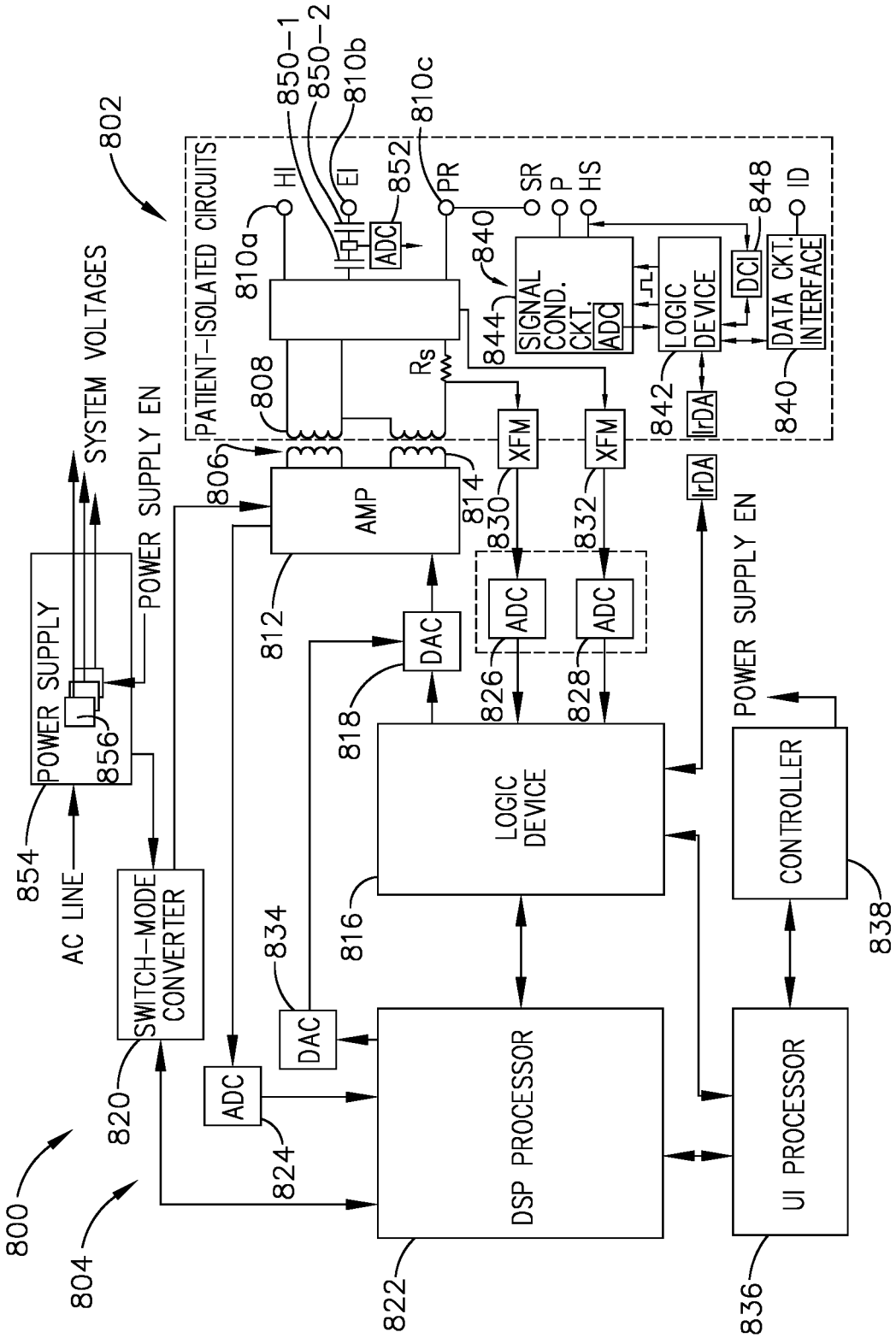
800
802
804
806
808
810a
810b
810c
812
814
816
818
820
822
824
826
828
830
832
834
836
838
840
842
844
848
850-1
850-2
852
854
856
PATIENT-ISOLATED CIRCUITS
HI
EI
PR
SR
P
HS
ID
ADC
DCI
DAC
AMP
XFM
IrDA
Rs
SIGNAL COND. CKT.
LOGIC DEVICE
DATA CKT. INTERFACE
SYSTEM VOLTAGES
POWER SUPPLY EN
POWER SUPPLY
AC LINE
SWITCH-MODE CONVERTER
DSP PROCESSOR
UI PROCESSOR
CONTROLLER

FIG. 20

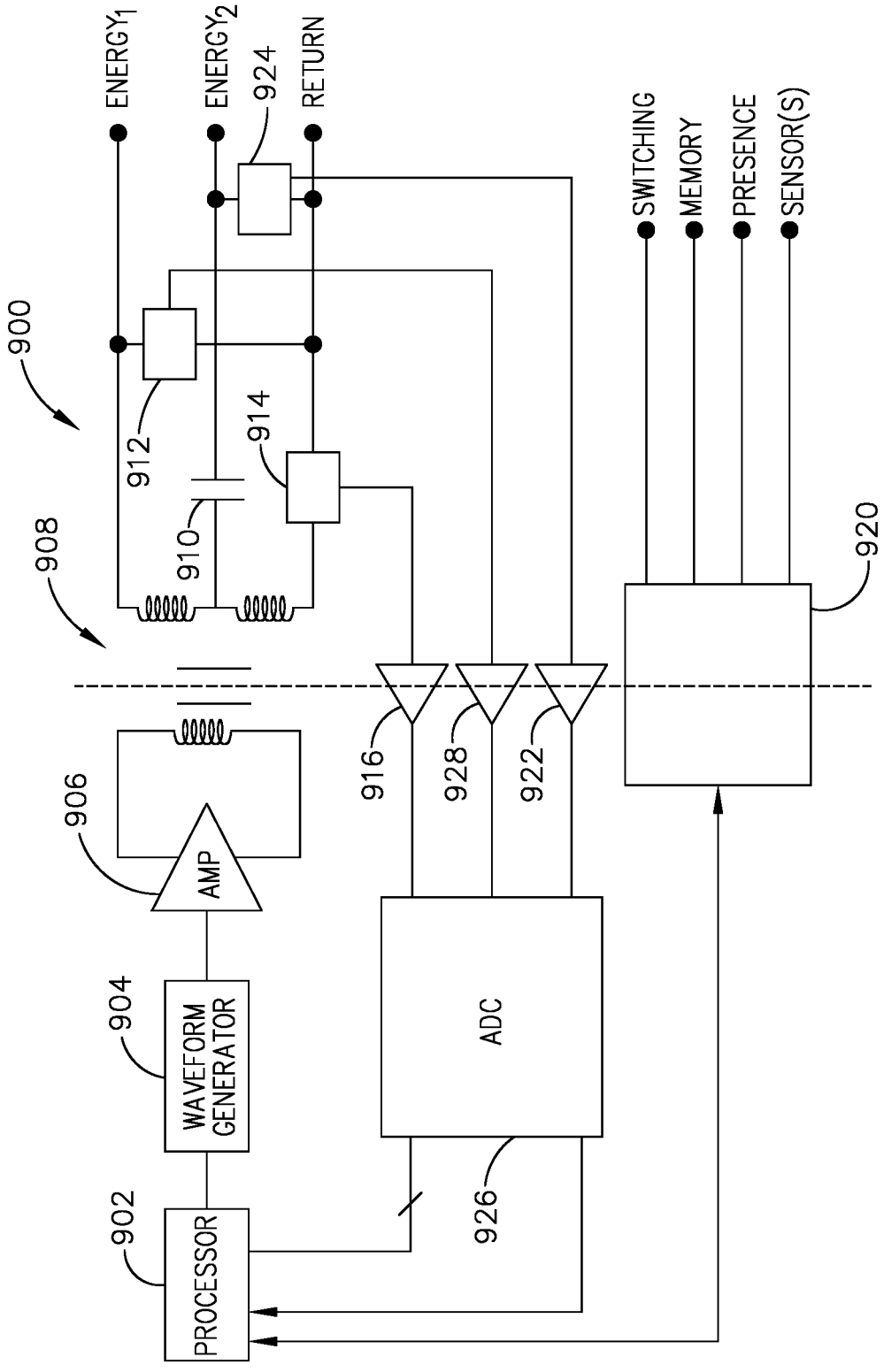
ENERGY1
ENERGY2
924
RETURN
SWITCHING
MEMORY
PRESENCE
SENSOR(S)
900
912
914
910
908
920
916
928
922
906
AMP
904
WAVEFORM GENERATOR
ADC
902
PROCESSOR
926

FIG. 21

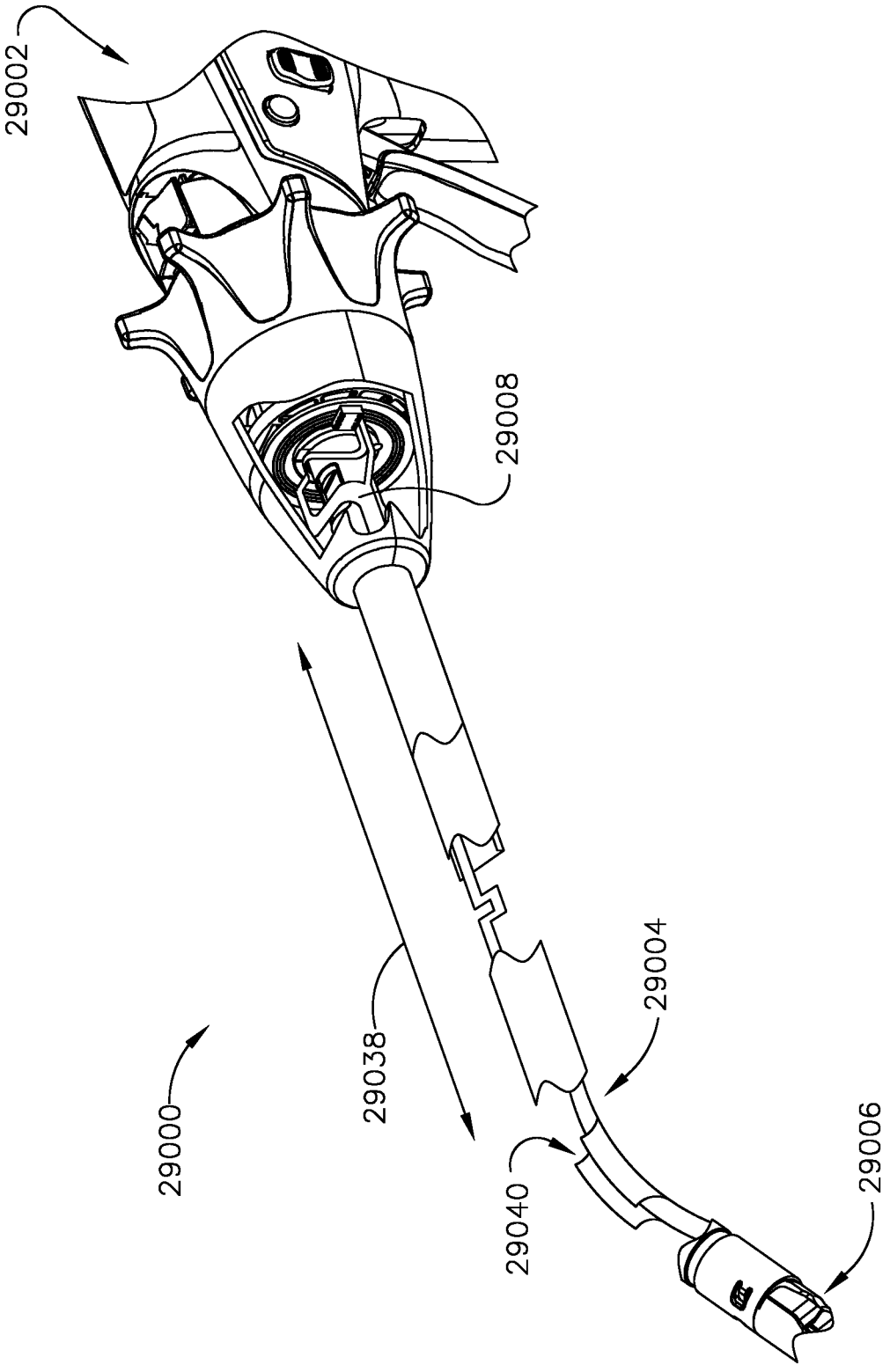


FIG. 22

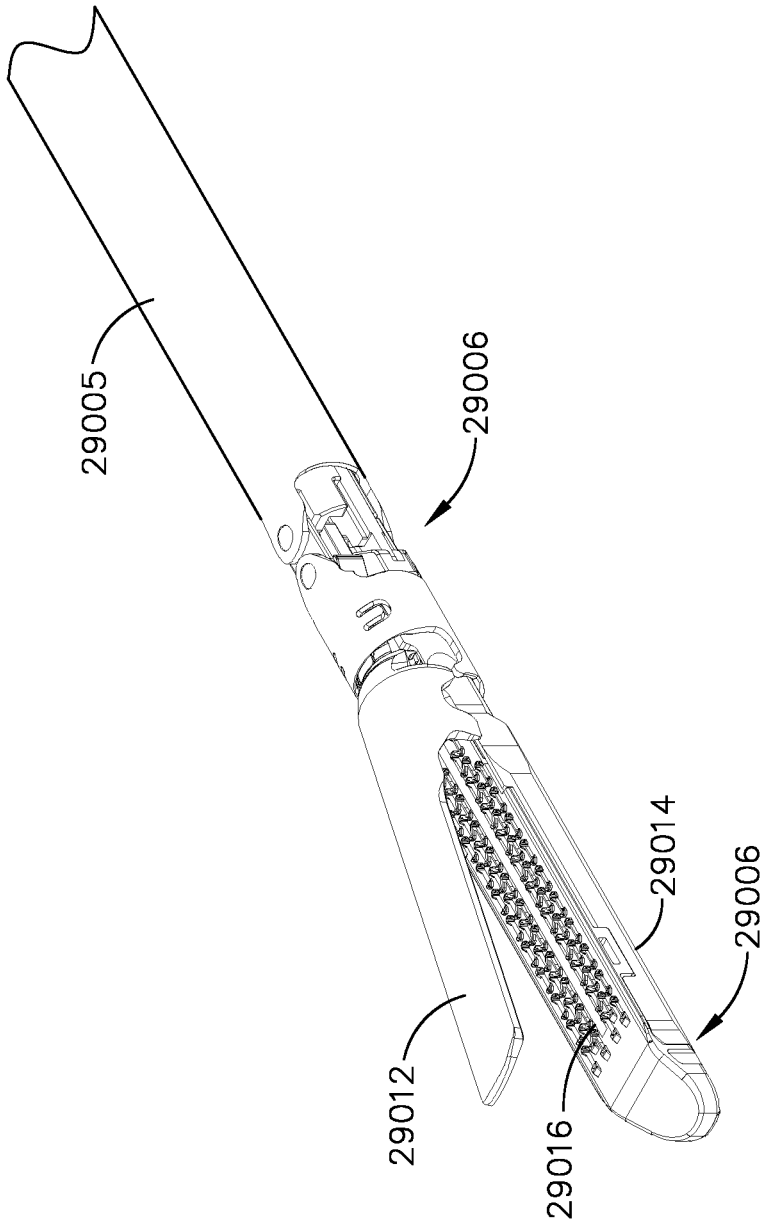


FIG. 23

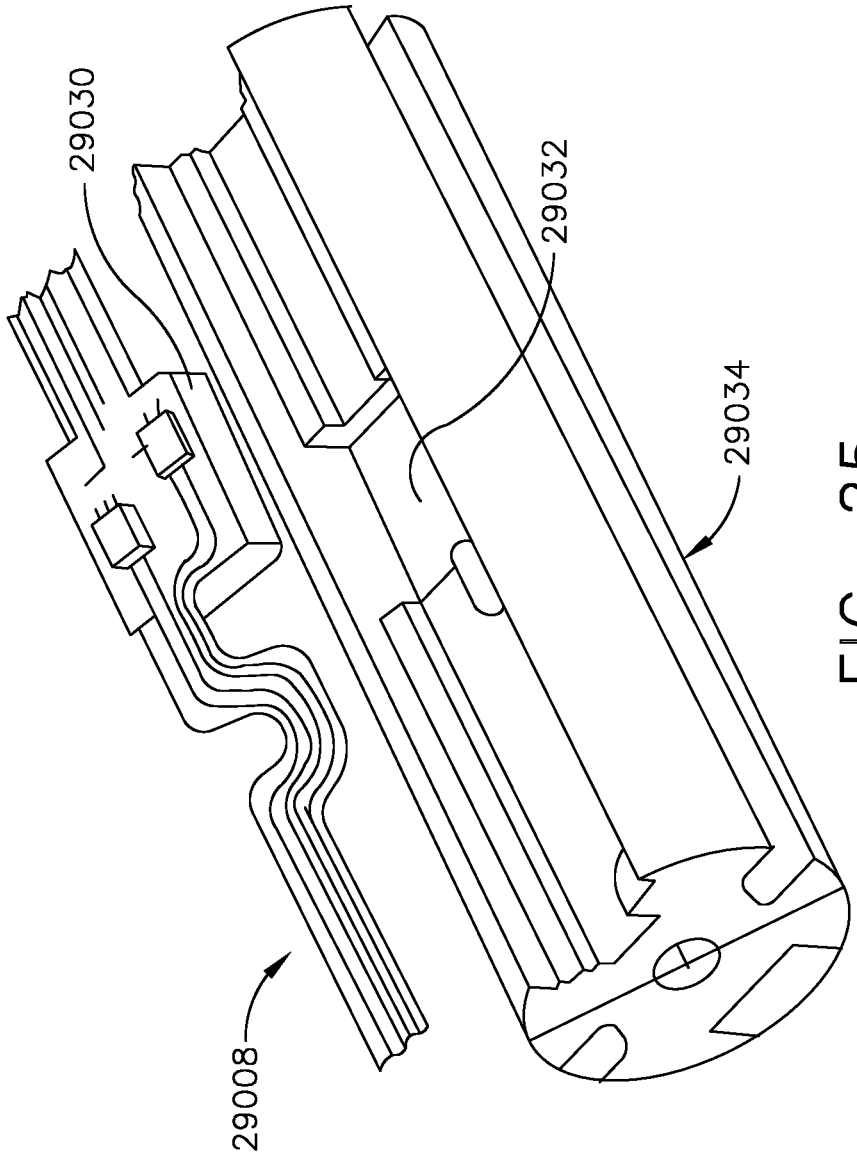


FIG. 25

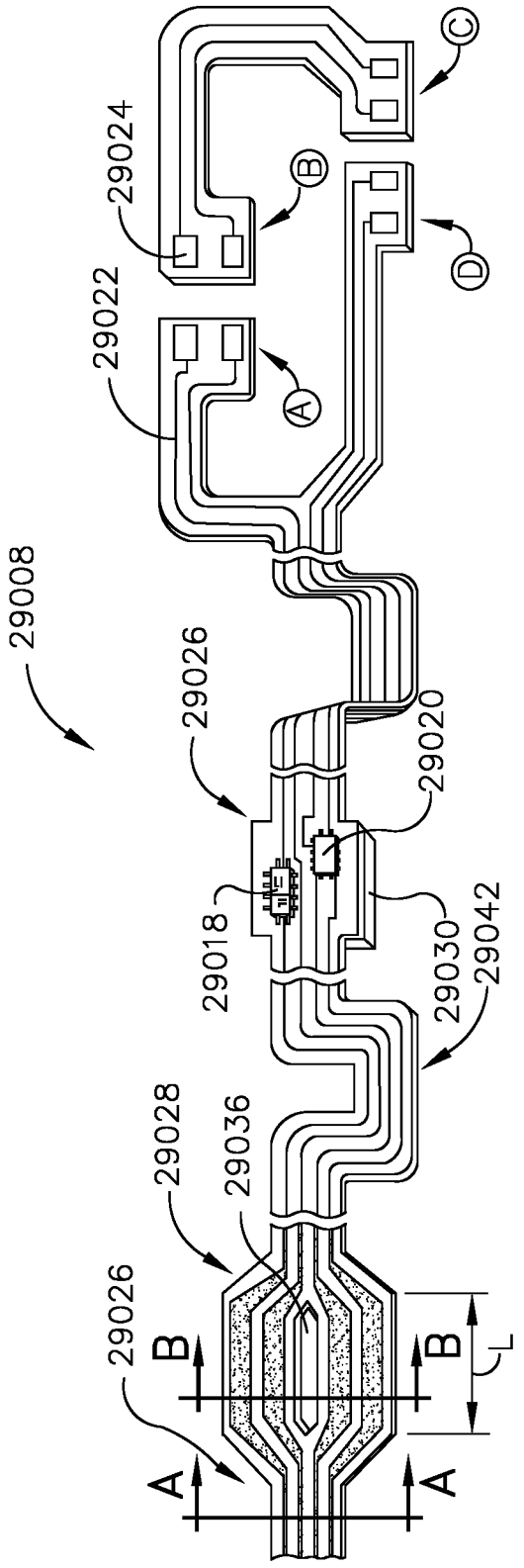


FIG. 24

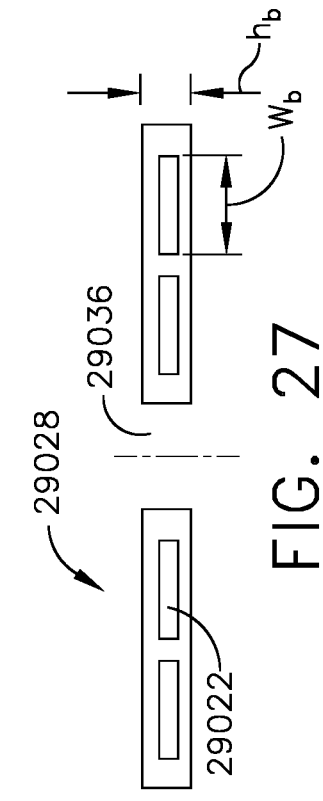


FIG. 27

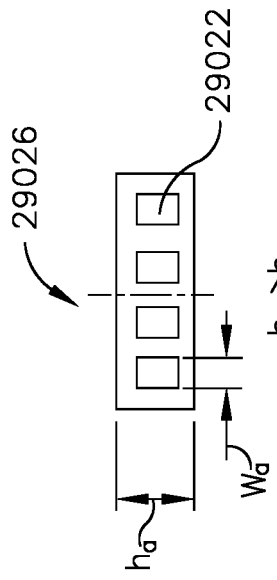


FIG. 26

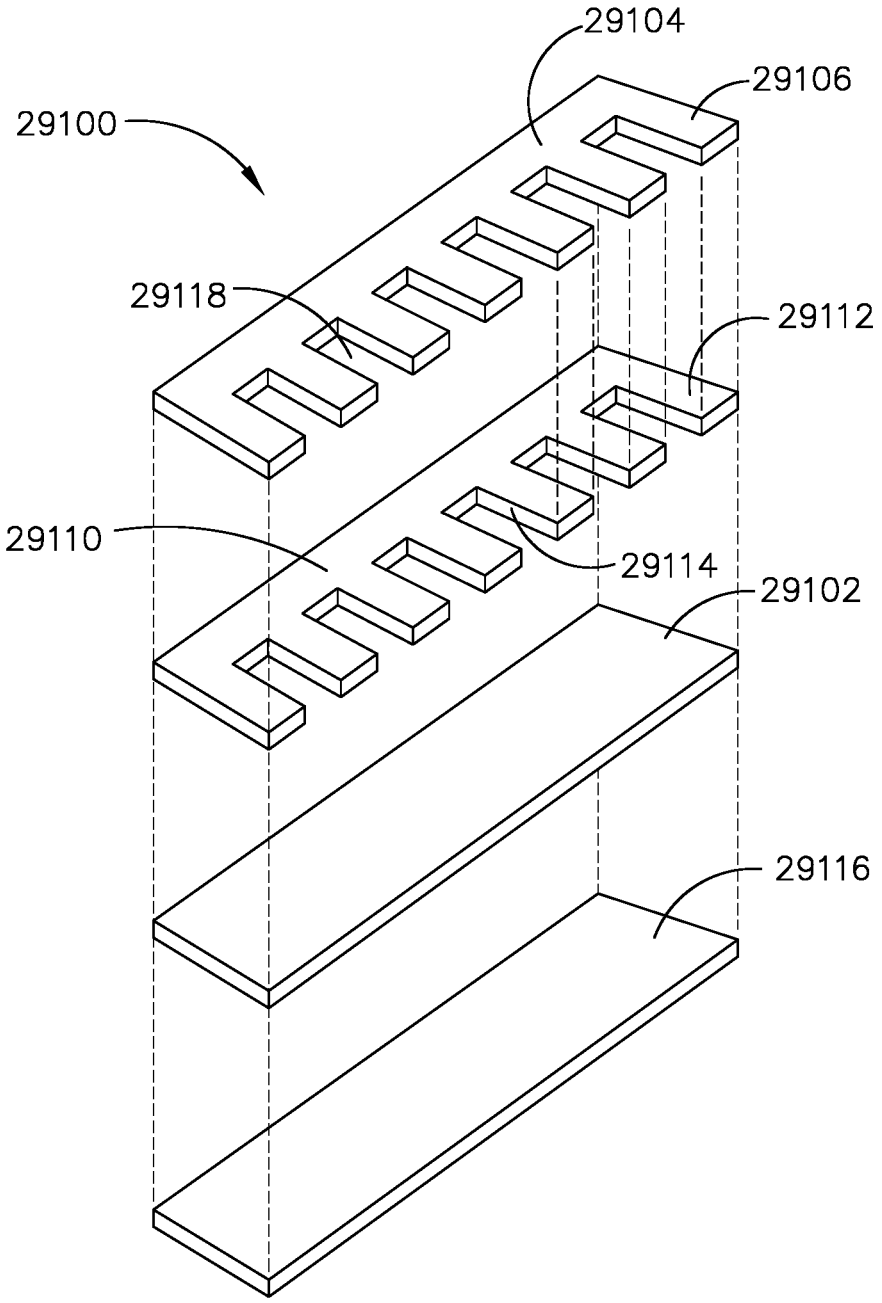


FIG. 28

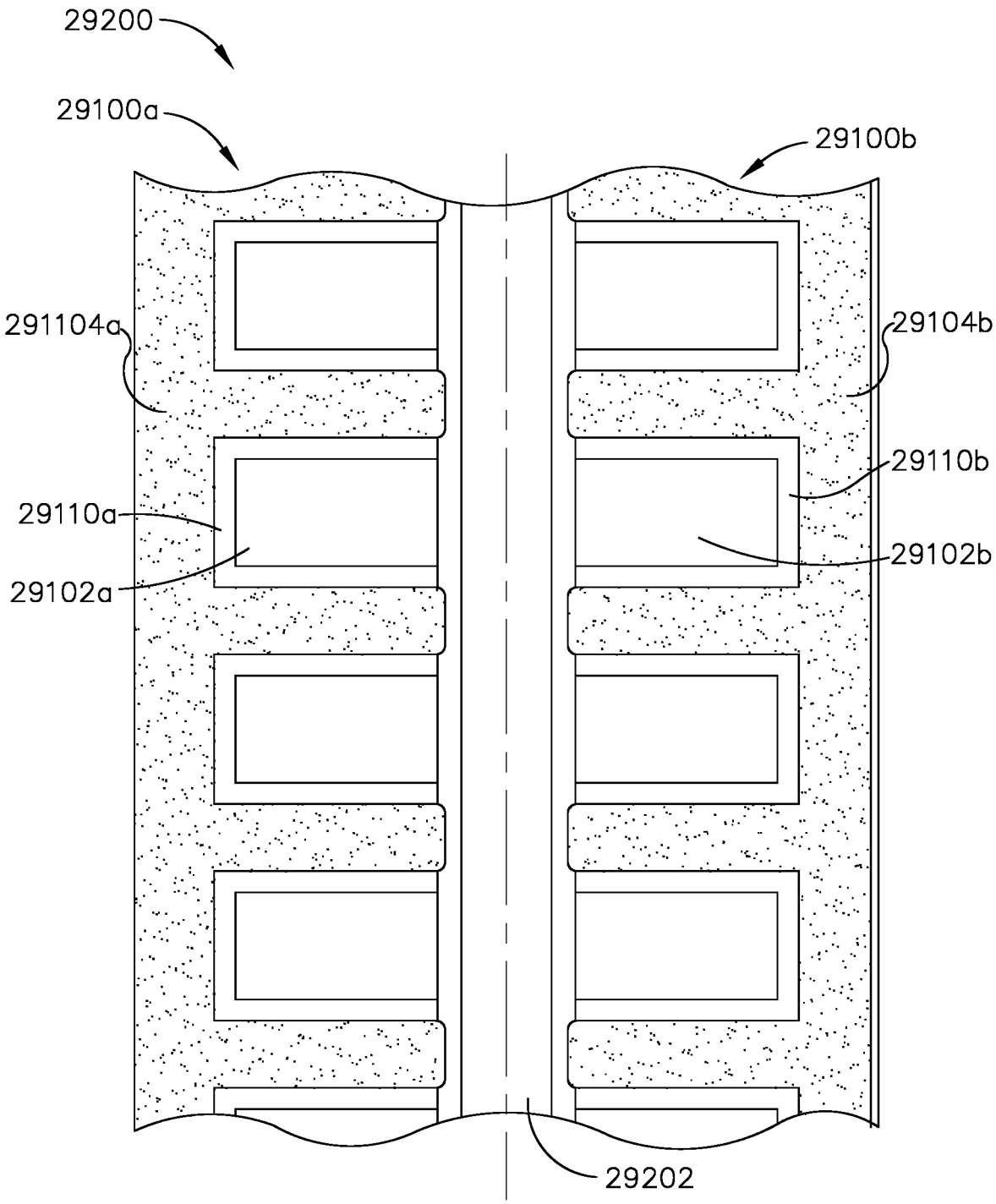
29200
29100a
29100b
291104a
29104b
29110b
29110a
29102b
29102a
29202

FIG. 29

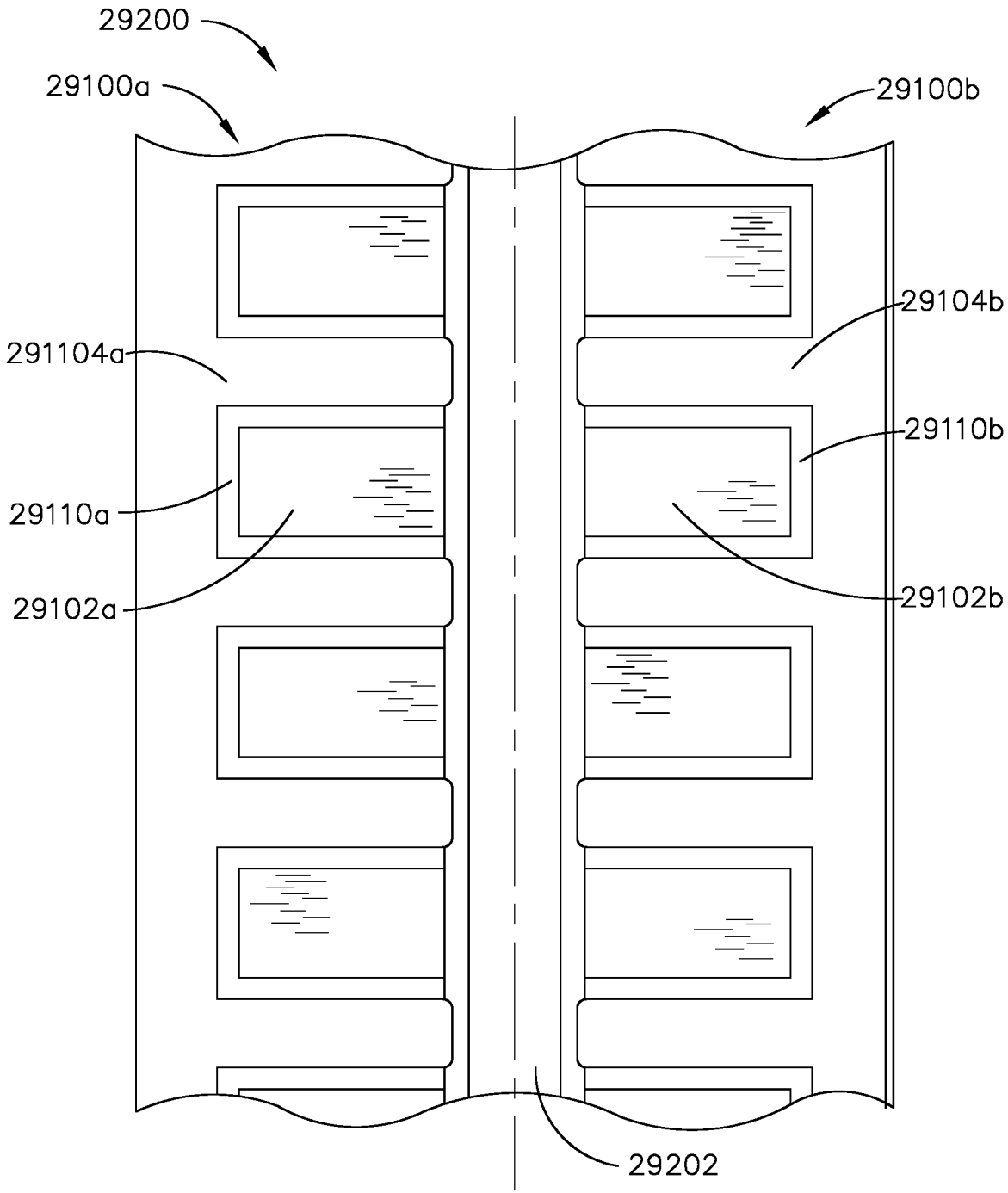
29200
29100a
29100b
29104b
291104a
29110b
29110a
29102a
29102b
29202

FIG. 30

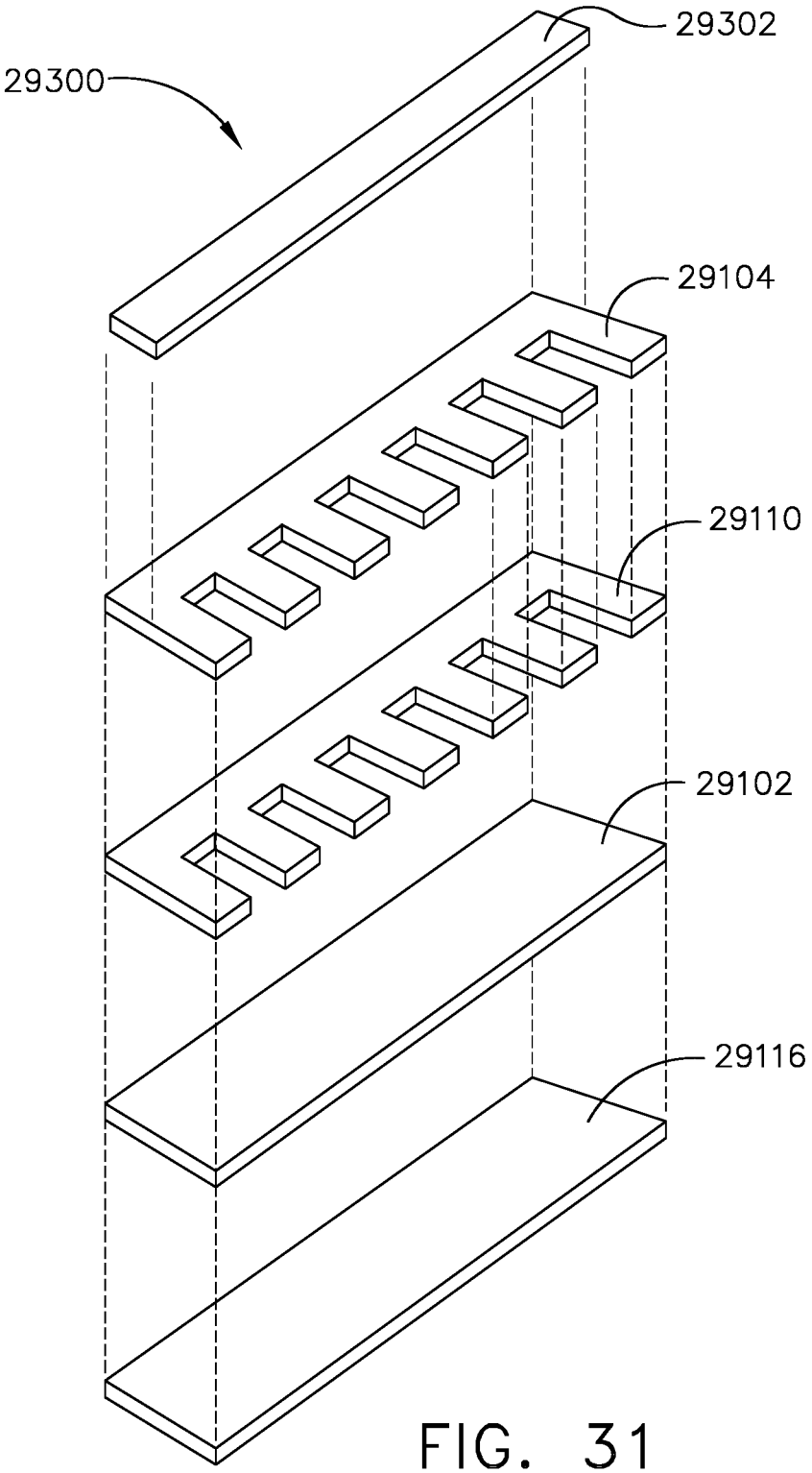


FIG. 31

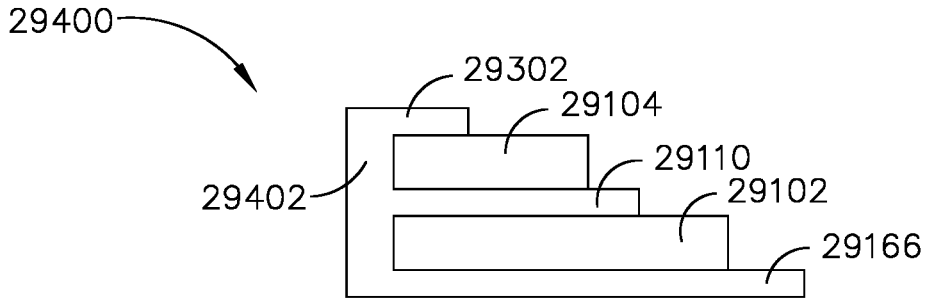
29400
29302
29104
29110
29102
29402
29166

FIG. 32

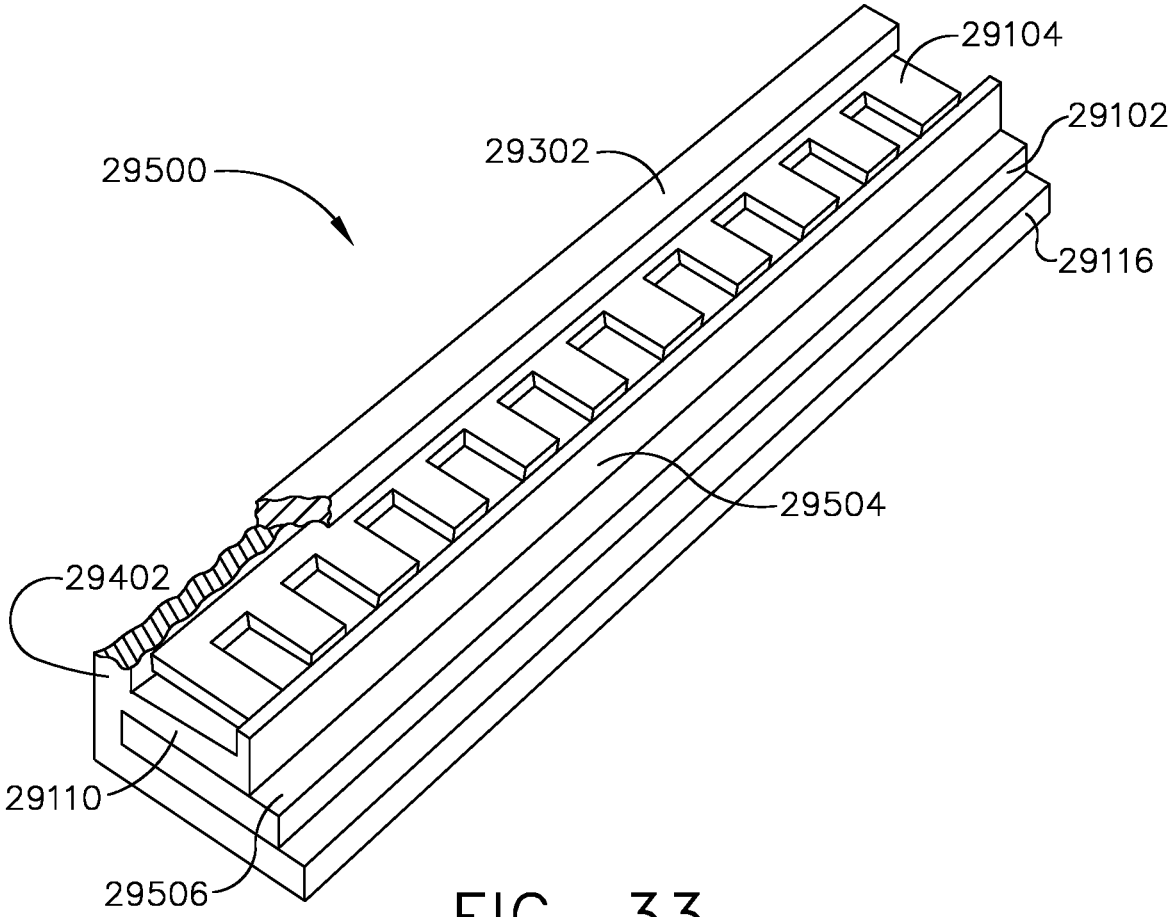
29104
29102
29302
29500
29116
29504
29402
29110
29506

FIG. 33

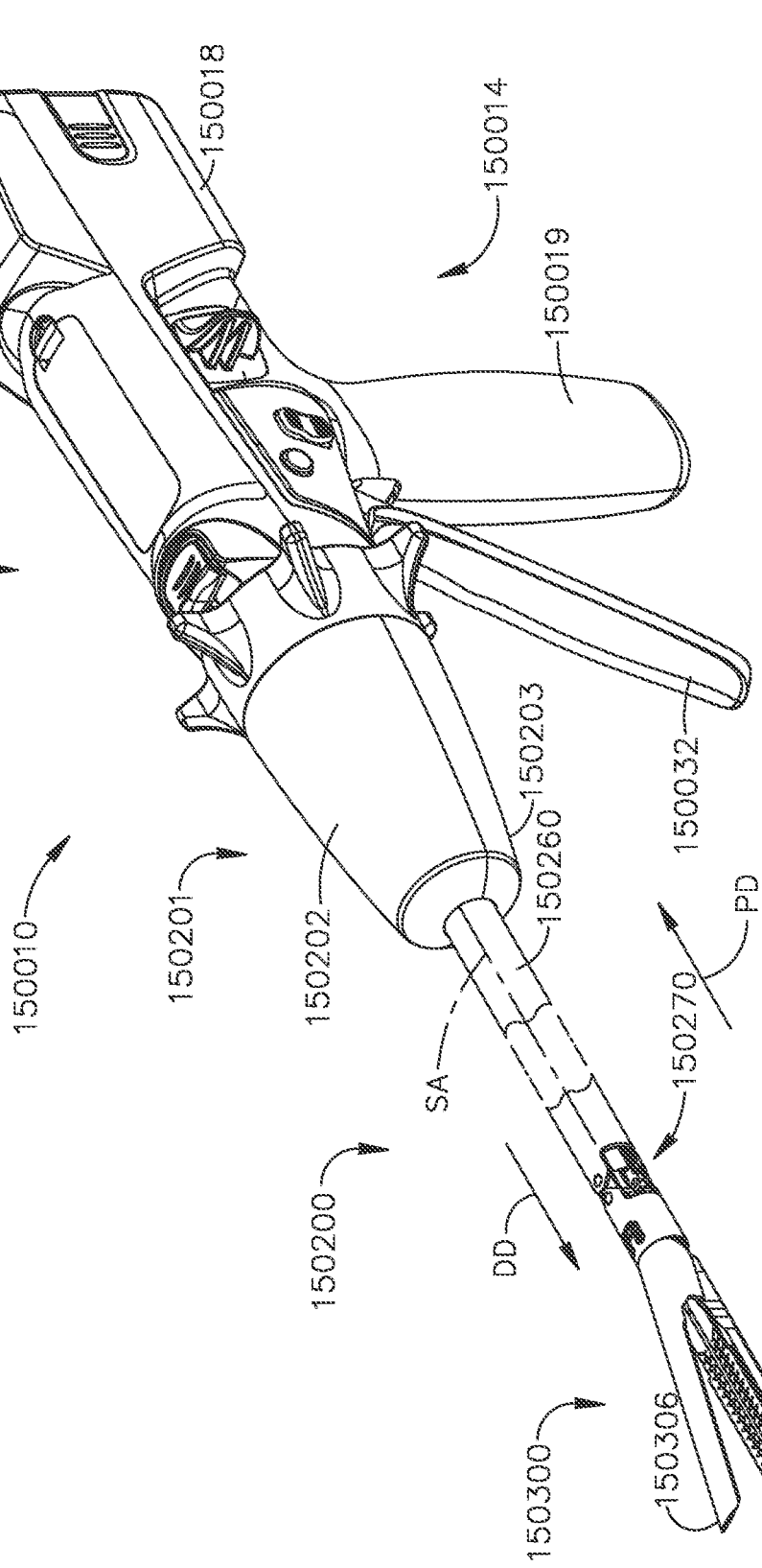
150045
150018
150014
150016
150019
150012
150032
150203
150260
150010
150201
150202
PD
150270
SA
150200
DD
150302
150304
150306
150300

FIG. 34

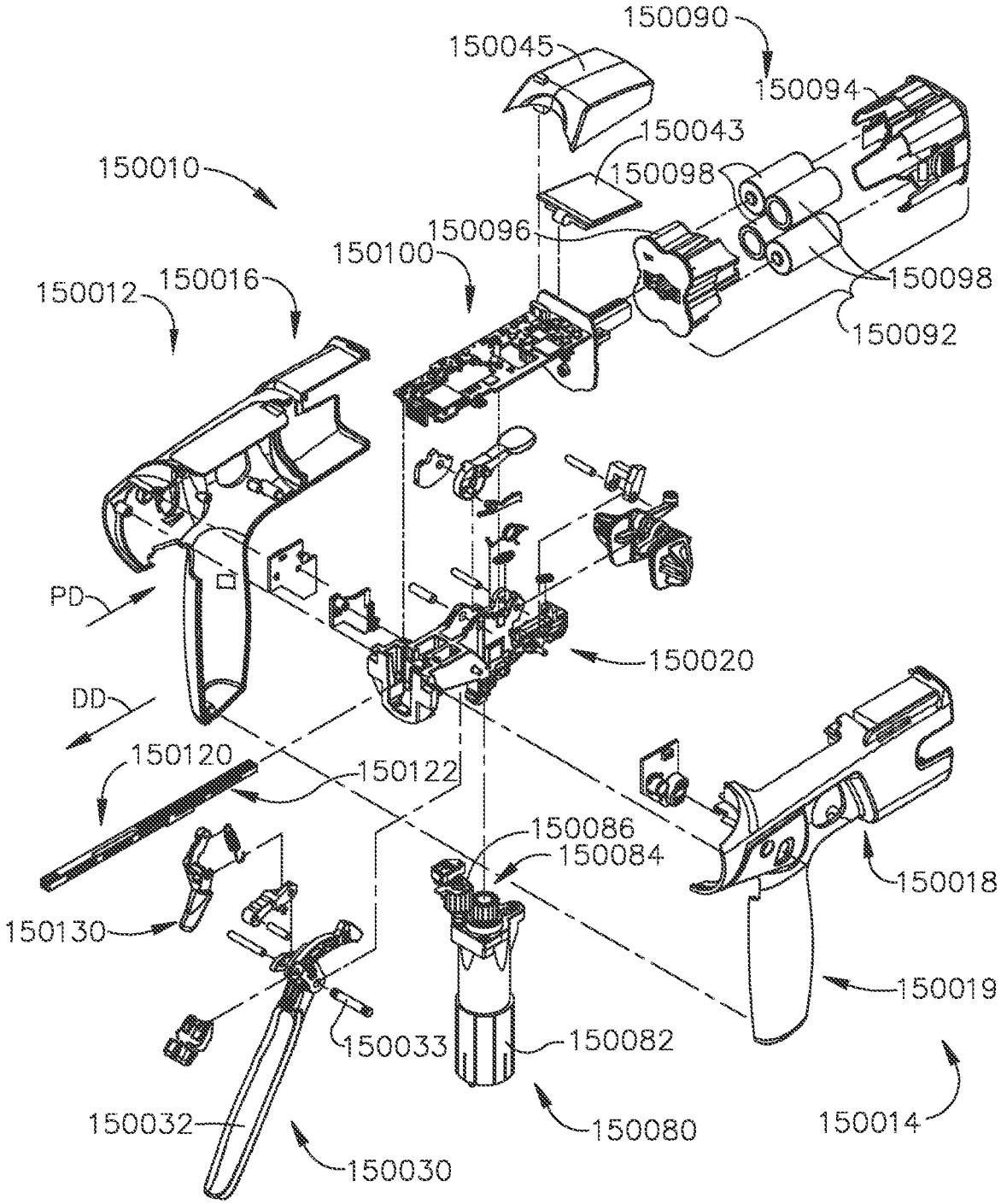
150090
150045
150094
150043
150010
150098
150096
150100
150098
150012
150016
150092
PD
150020
DD
150120
150122
150086
150084
150018
150130
150019
150033
150082
150032
150080
150014
150030

FIG. 35

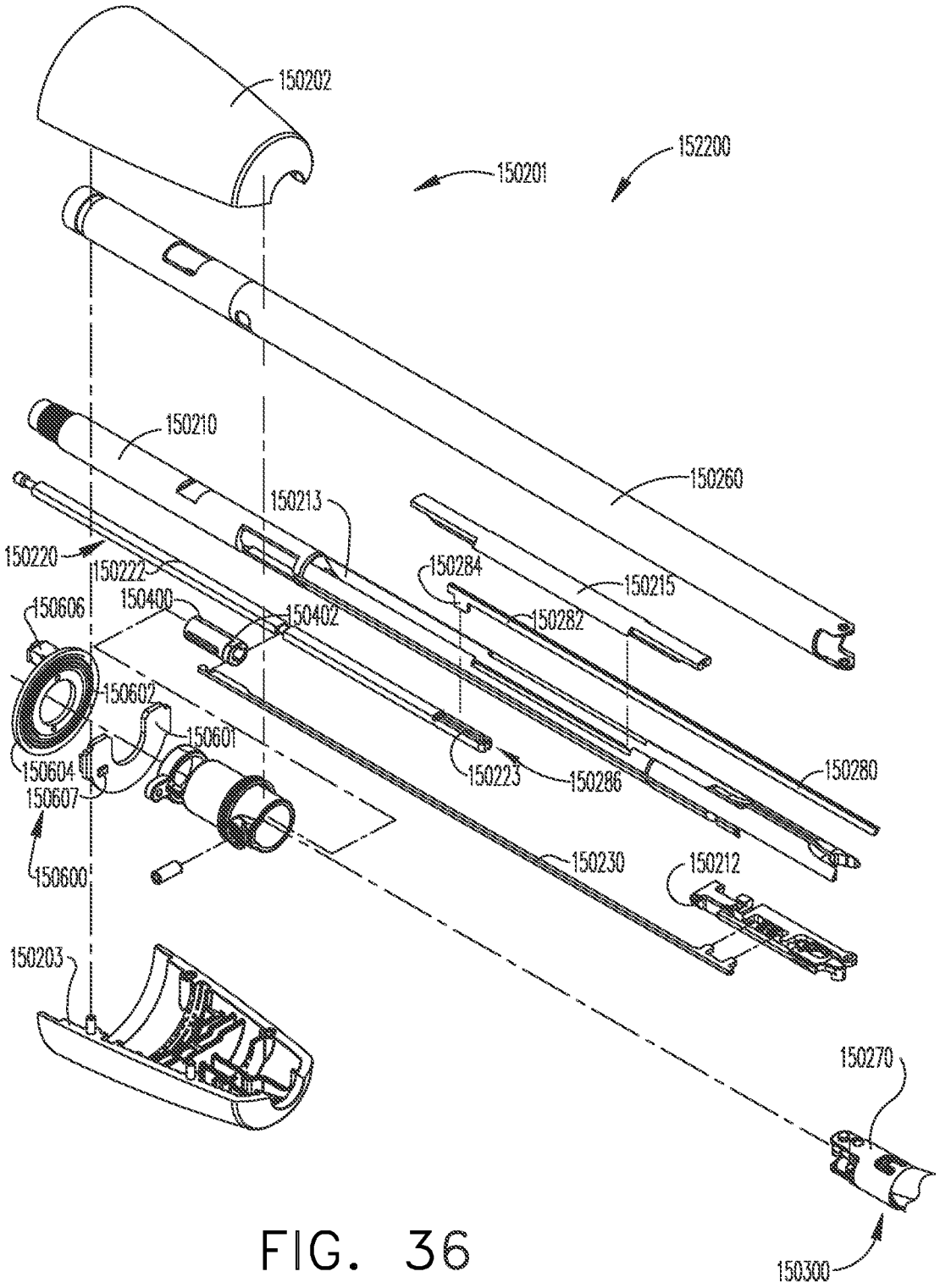
150202
150201
152200
150210
150260
150213
150220
150222
150284
150215
150606
150400
150402
150282
150602
150601
150604
150607
150223
150286
150280
150600
150230
150212
150203
150270
150300

FIG. 36

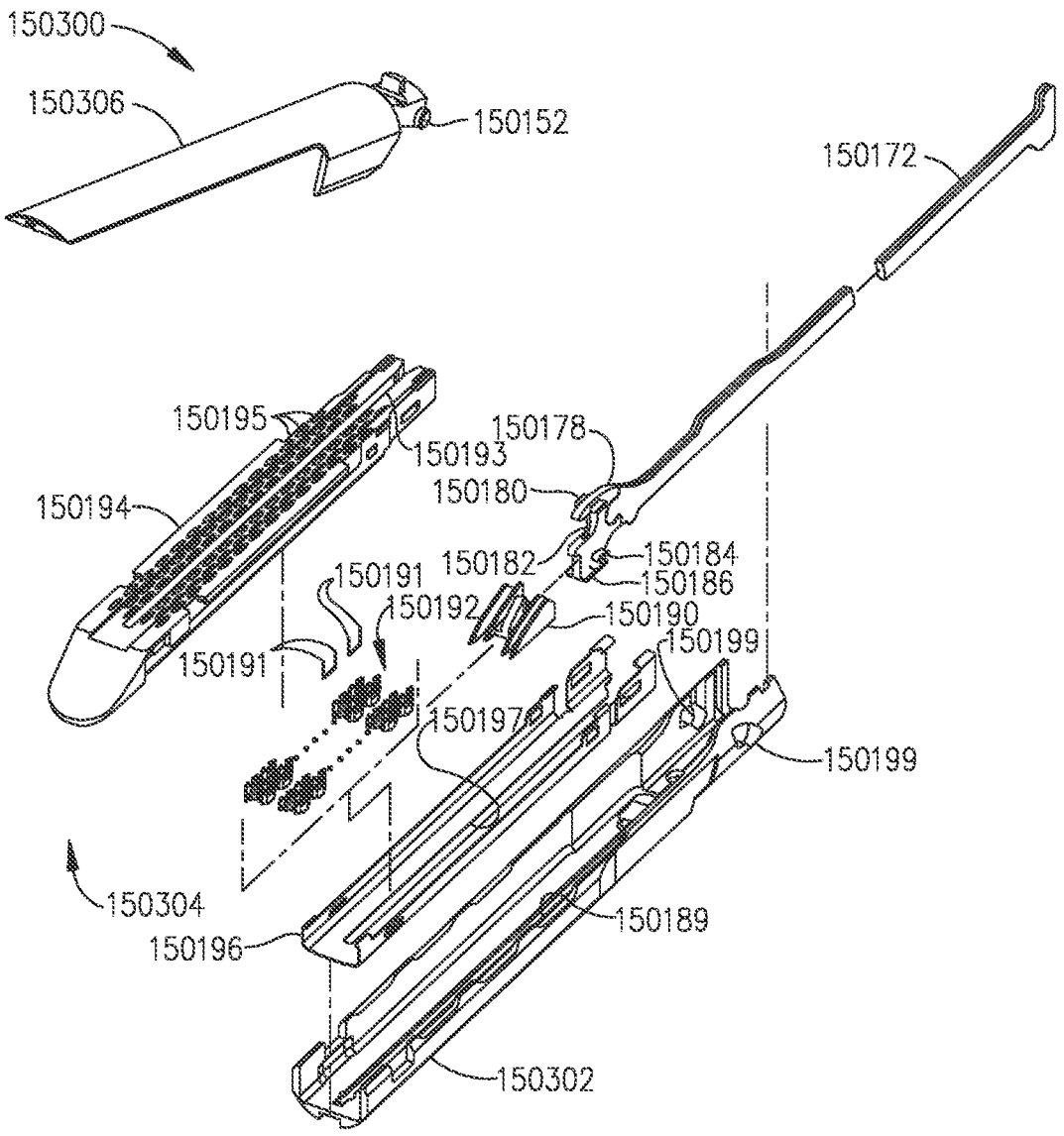
150300
150306
150152
150172
150195
150193
150178
150180
150194
150182
150184
150186
150191
150192
150190
150199
150191
150197
150199
150304
150189
150196
150302

FIG. 37

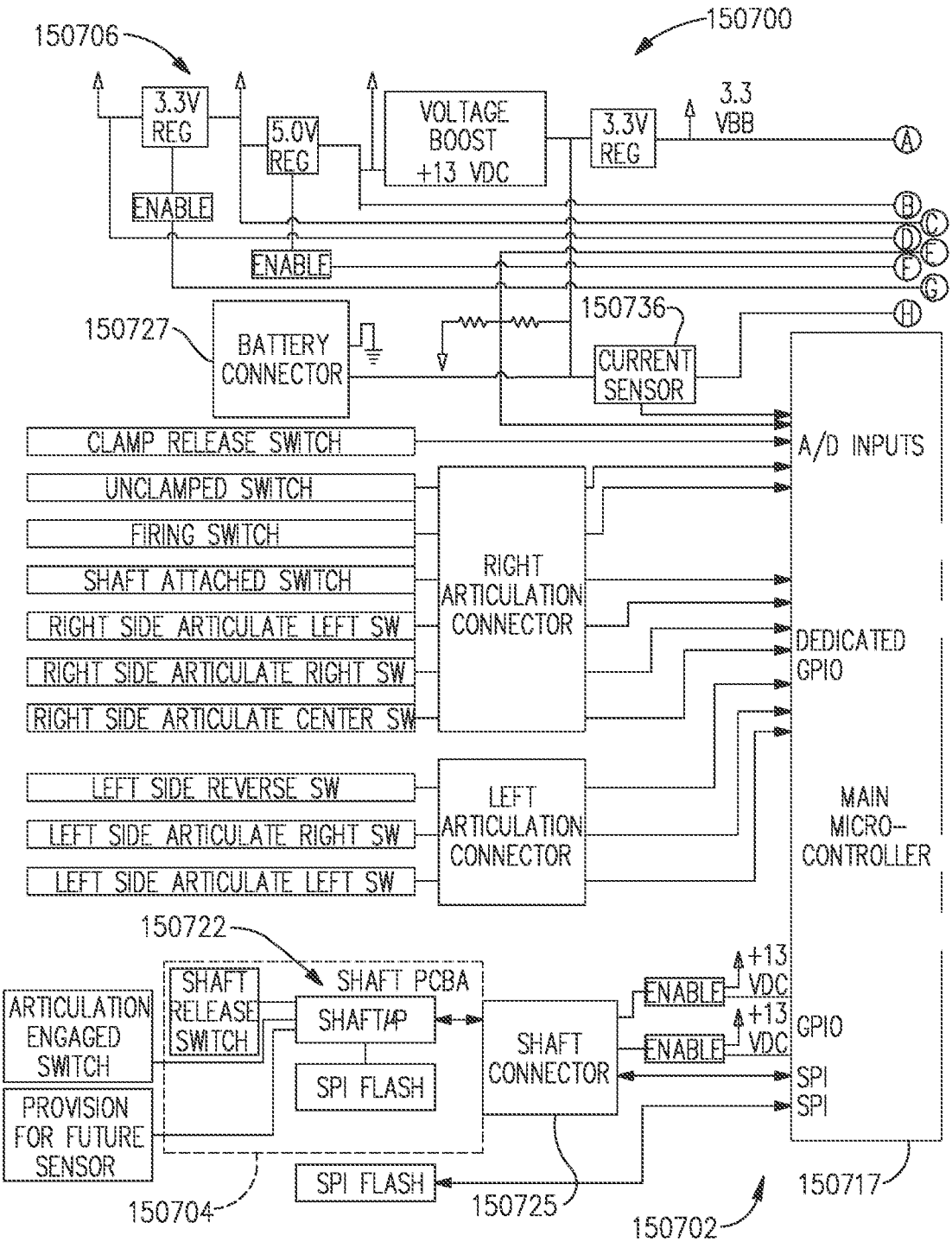
150706
150700
3.3V REG
5.0V REG
VOLTAGE BOOST +13 VDC
3.3V REG
3.3 VBB
A
ENABLE
B
C
D
E
F
G
ENABLE
150727
BATTERY CONNECTOR
150736
CURRENT SENSOR
H
CLAMP RELEASE SWITCH
UNCLAMPED SWITCH
FIRING SWITCH
SHAFT ATTACHED SWITCH
RIGHT SIDE ARTICULATE LEFT SW
RIGHT SIDE ARTICULATE RIGHT SW
RIGHT SIDE ARTICULATE CENTER SW
RIGHT ARTICULATION CONNECTOR
A/D INPUTS
DEDICATED GPIO
LEFT SIDE REVERSE SW
LEFT SIDE ARTICULATE RIGHT SW
LEFT SIDE ARTICULATE LEFT SW
LEFT ARTICULATION CONNECTOR
MAIN MICRO-CONTROLLER
150722
SHAFT PCBA
ARTICULATION ENGAGED SWITCH
SHAFT RELEASE SWITCH
SHAFT I/P
SPI FLASH
PROVISION FOR FUTURE SENSOR
SHAFT CONNECTOR
ENABLE
+13 VDC
ENABLE
+13 VDC
GPIO
SPI
SPI
SPI FLASH
150704
150725
150702
150717

FIG. 38A

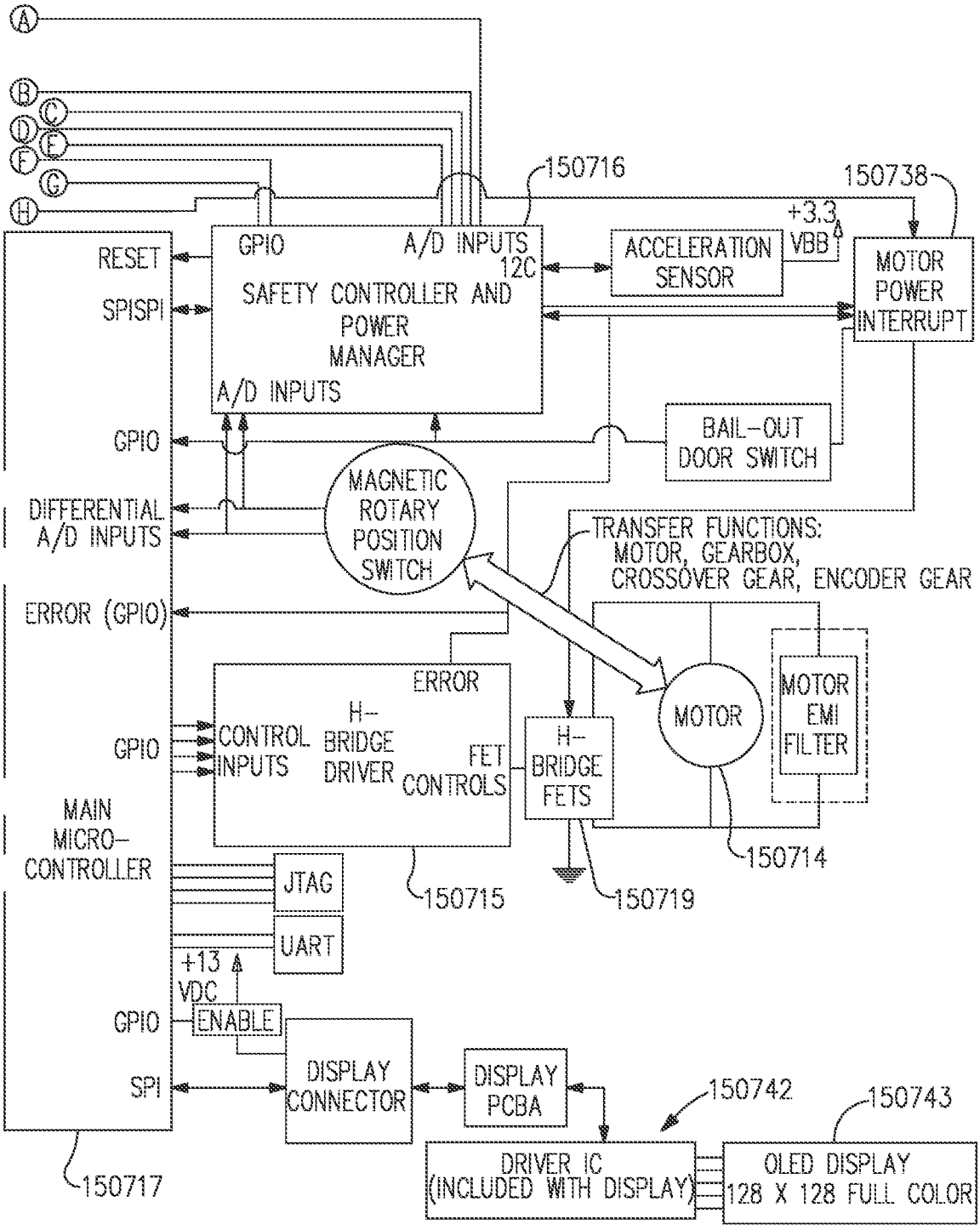
A
B
C
D
E
F
G
H
150716
150738
+3.3
VBB
GPIO
A/D INPUTS
12C
RESET
SPISPI
SAFETY CONTROLLER AND
POWER
MANAGER
A/D INPUTS
ACCELERATION
SENSOR
MOTOR
POWER
INTERRUPT
GPIO
BAIL-OUT
DOOR SWITCH
MAGNETIC
ROTARY
POSITION
SWITCH
DIFFERENTIAL
A/D INPUTS
TRANSFER FUNCTIONS:
MOTOR, GEARBOX,
CROSSOVER GEAR, ENCODER GEAR
ERROR (GPIO)
ERROR
GPIO
CONTROL
INPUTS
H-
BRIDGE
DRIVER
FET
CONTROLS
H-
BRIDGE
FETS
MOTOR
MOTOR
EMI
FILTER
MAIN
MICRO-
CONTROLLER
JTAG
UART
150715
150719
150714
+13
VDC
GPIO
ENABLE
SPI
DISPLAY
CONNECTOR
DISPLAY
PCBA
150742
150743
DRIVER IC
(INCLUDED WITH DISPLAY)
OLED DISPLAY
128 X 128 FULL COLOR
150717

FIG. 38B

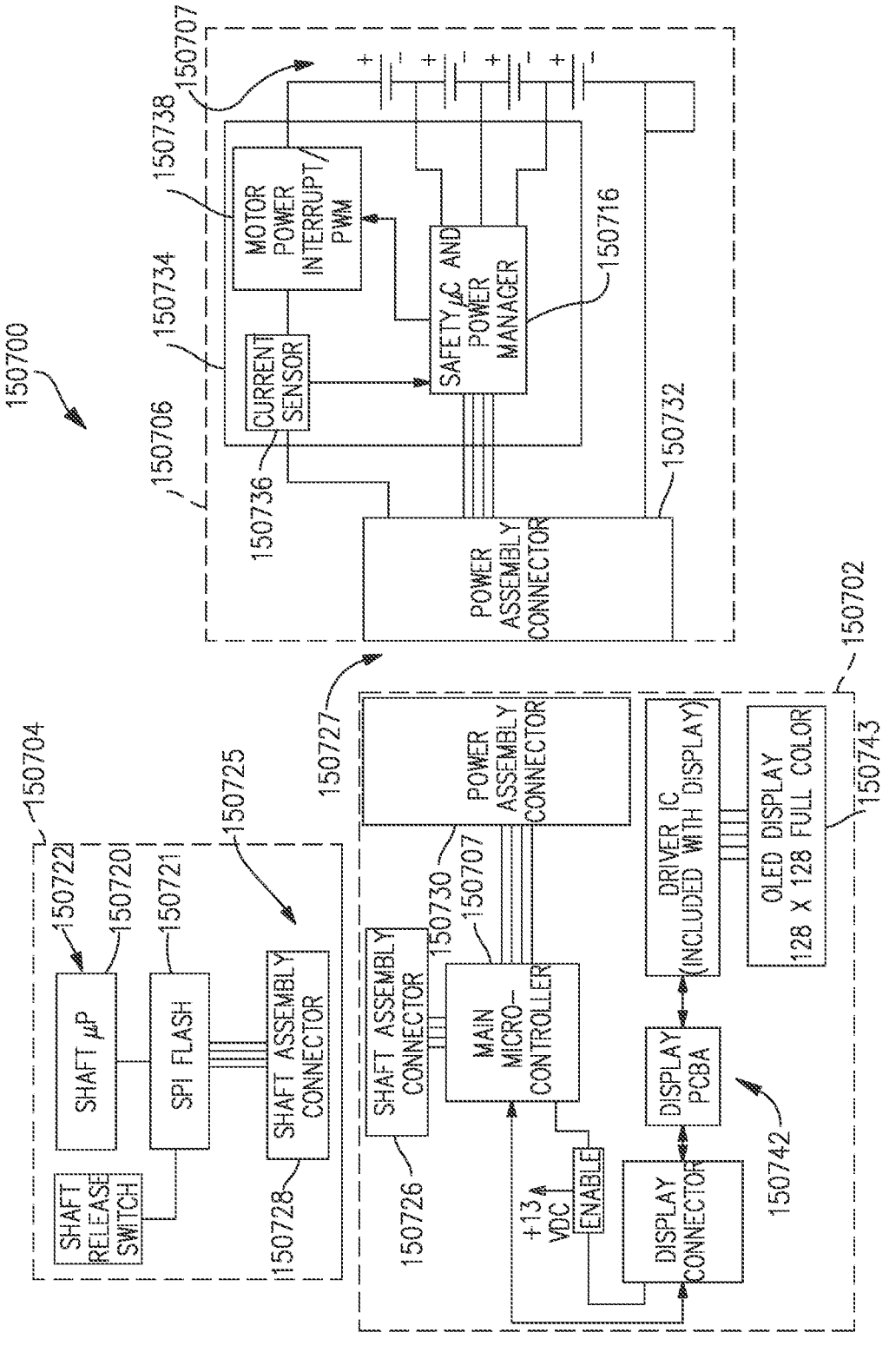
150700
150704
150722
150720
150721
150725
150727
150702
150707
150738
150734
150706
150736
150716
150732
150730
150726
150728
150742
150743
SHAFT RELEASE SWITCH
SHAFT μP
SPI FLASH
SHAFT ASSEMBLY CONNECTOR
SHAFT ASSEMBLY CONNECTOR
MAIN MICRO-CONTROLLER
POWER ASSEMBLY CONNECTOR
MOTOR POWER INTERRUPT PWM
CURRENT SENSOR
SAFETY μC AND POWER MANAGER
POWER ASSEMBLY CONNECTOR
+13 VDC
ENABLE
DISPLAY CONNECTOR
DISPLAY PCBA
DRIVER IC (INCLUDED WITH DISPLAY)
OLED DISPLAY 128 X 128 FULL COLOR

FIG. 39

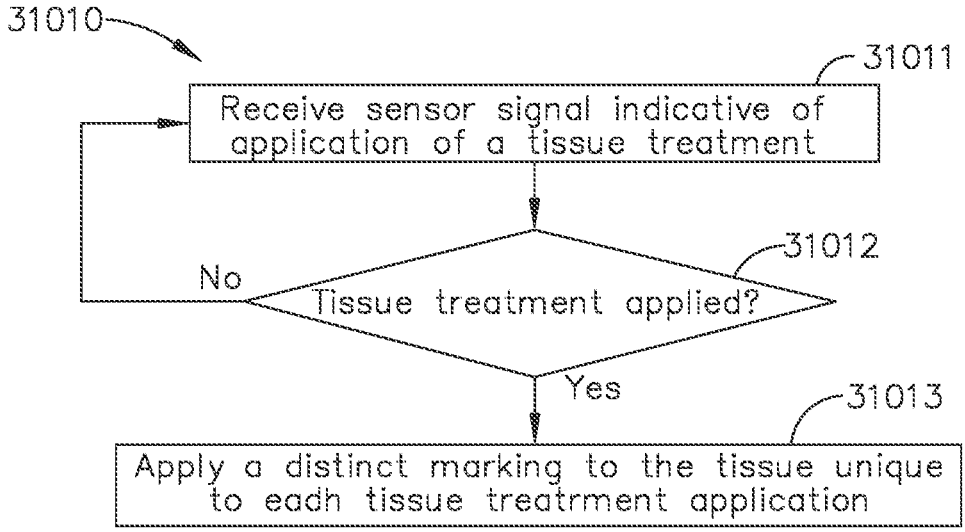


FIG. 40

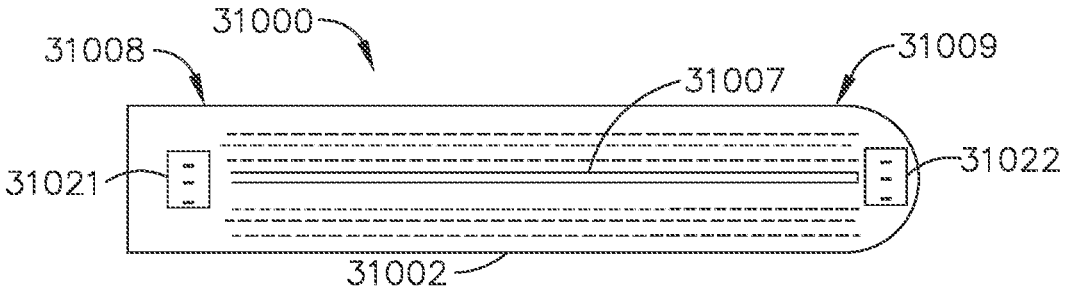


FIG. 41

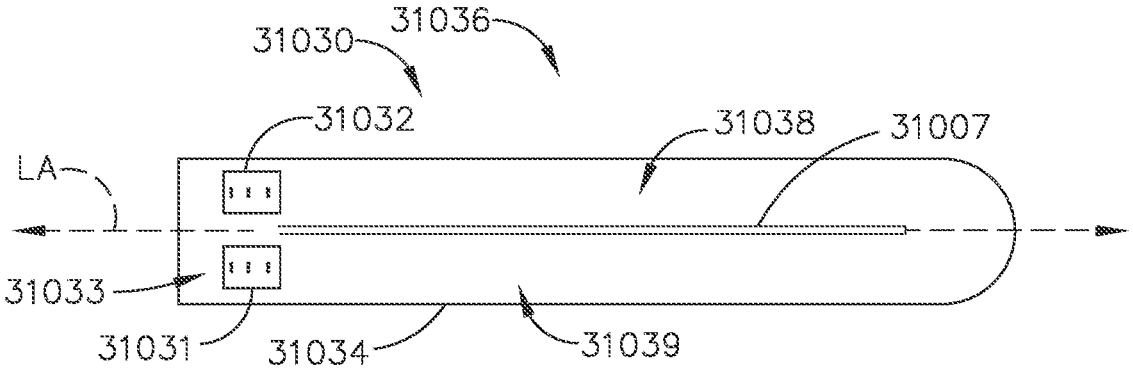


FIG. 42

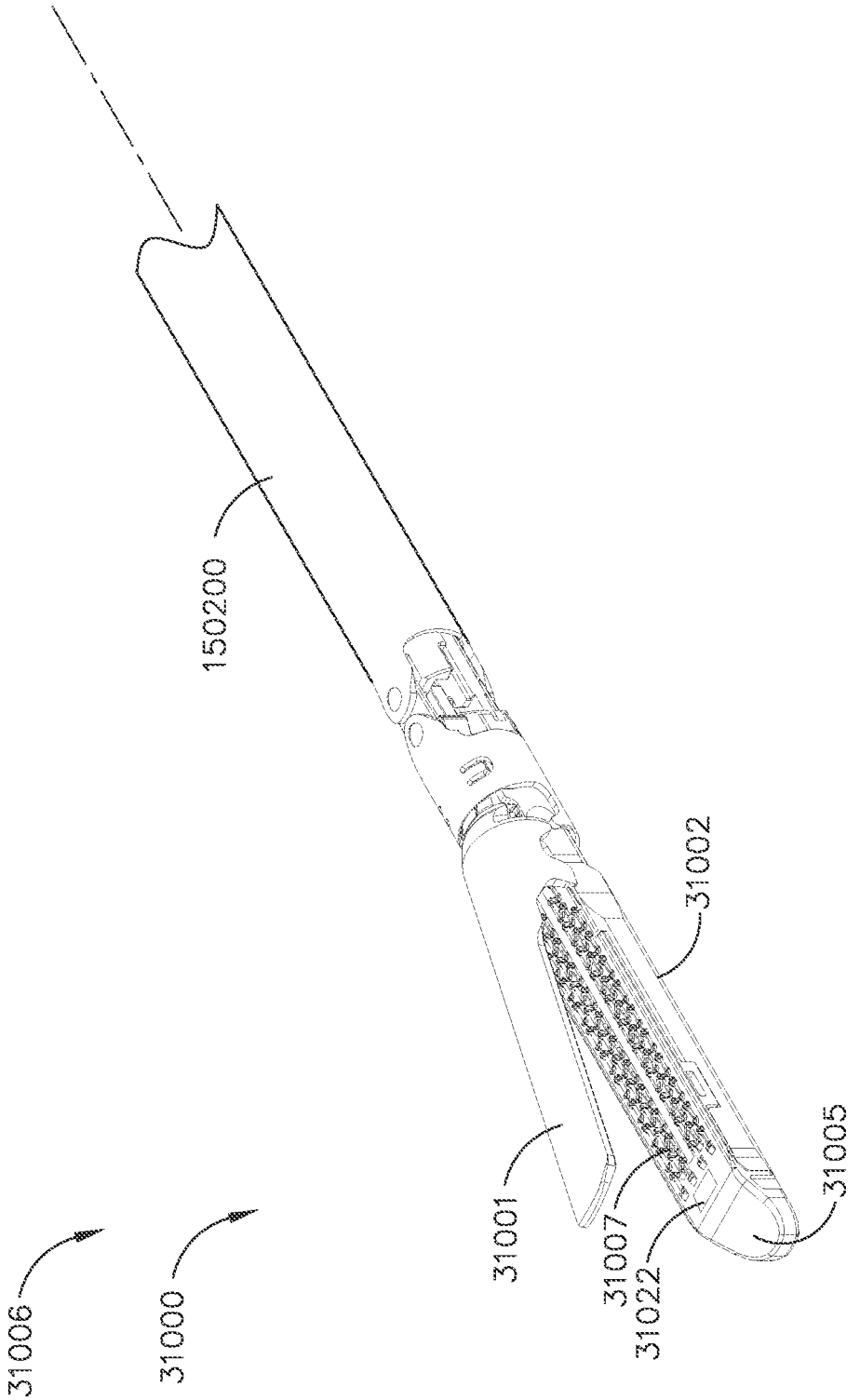


FIG. 43

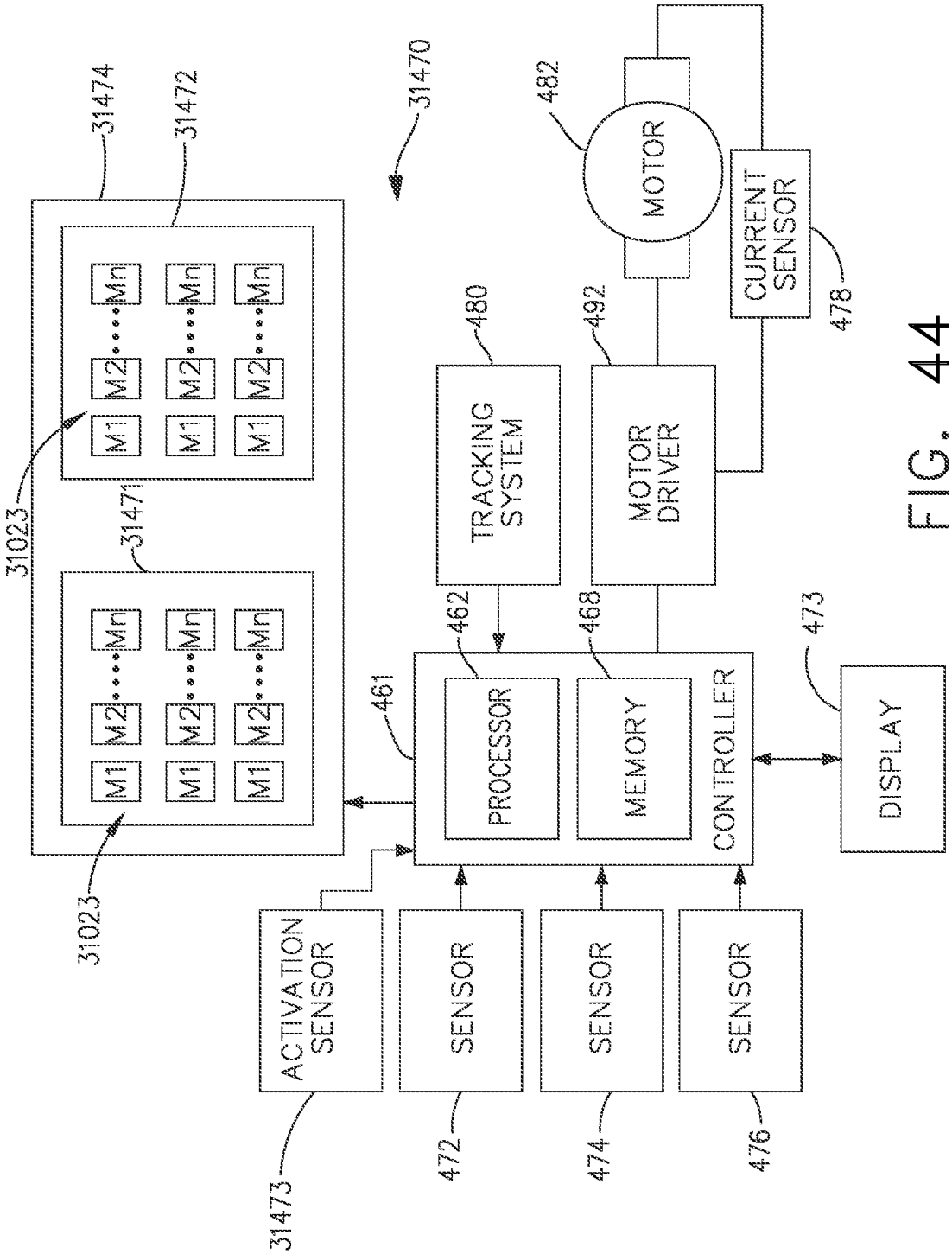
31474
31472
31470
482
MOTOR
CURRENT SENSOR
478
480
492
TRACKING SYSTEM
MOTOR DRIVER
31023
31471
M1
M2
Mn
462
468
473
461
PROCESSOR
MEMORY
CONTROLLER
DISPLAY
ACTIVATION SENSOR
SENSOR
SENSOR
SENSOR
31473
472
474
476

FIG. 44

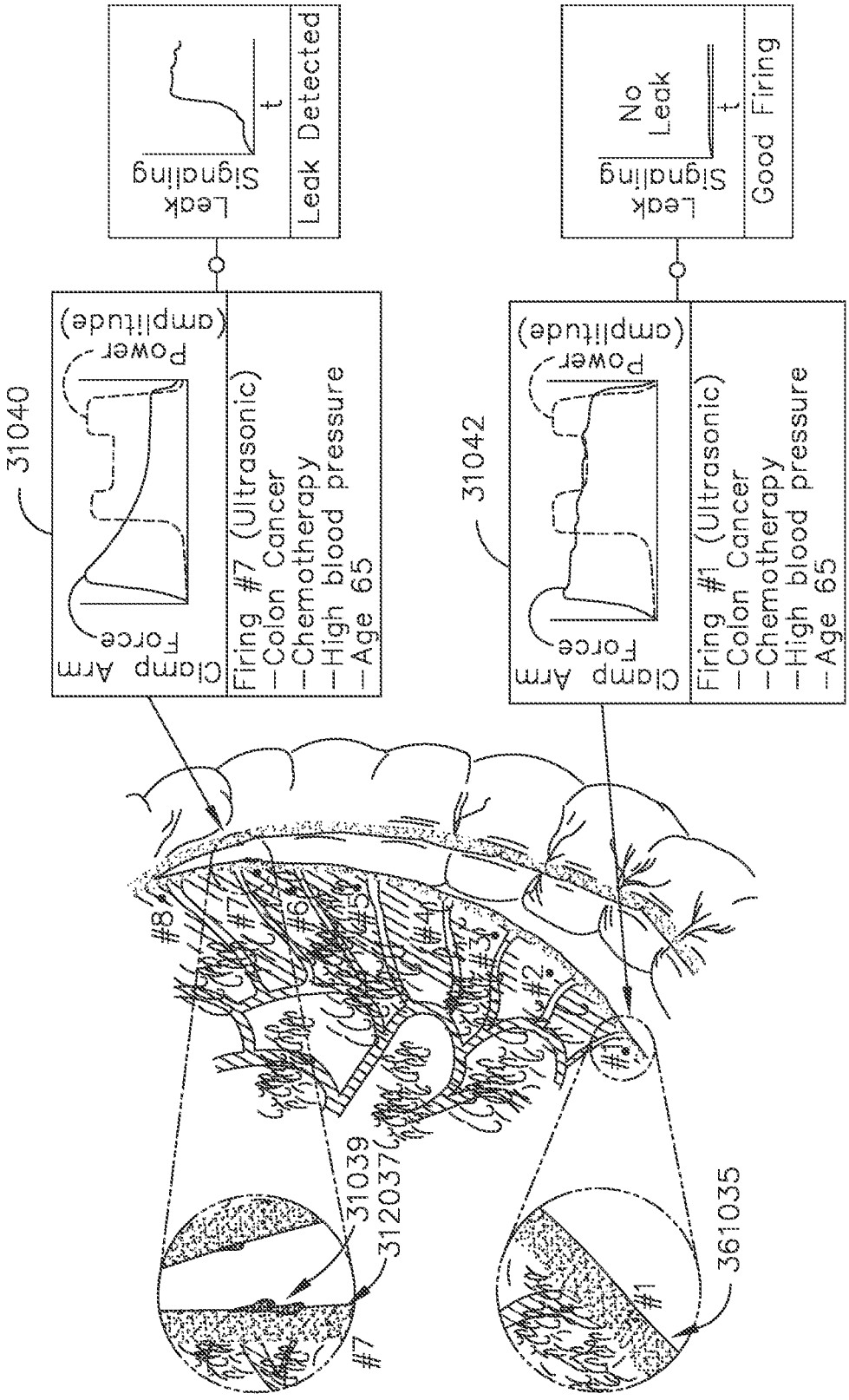
Leak Signaling
t
Leak Detected
No Leak
Leak Signaling
t
Good Firing
31040
(amplitude)
Power
Force
Clamp Arm
Firing #7 (Ultrasonic)
—Colon Cancer
—Chemotherapy
—High blood pressure
—Age 65
31042
(amplitude)
Power
Force
Clamp Arm
Firing #1 (Ultrasonic)
—Colon Cancer
—Chemotherapy
—High blood pressure
—Age 65
#8
#7
#6
#5
#4
#3
#2
#1
31039
3120376
#7
361035
#1

FIG. 45

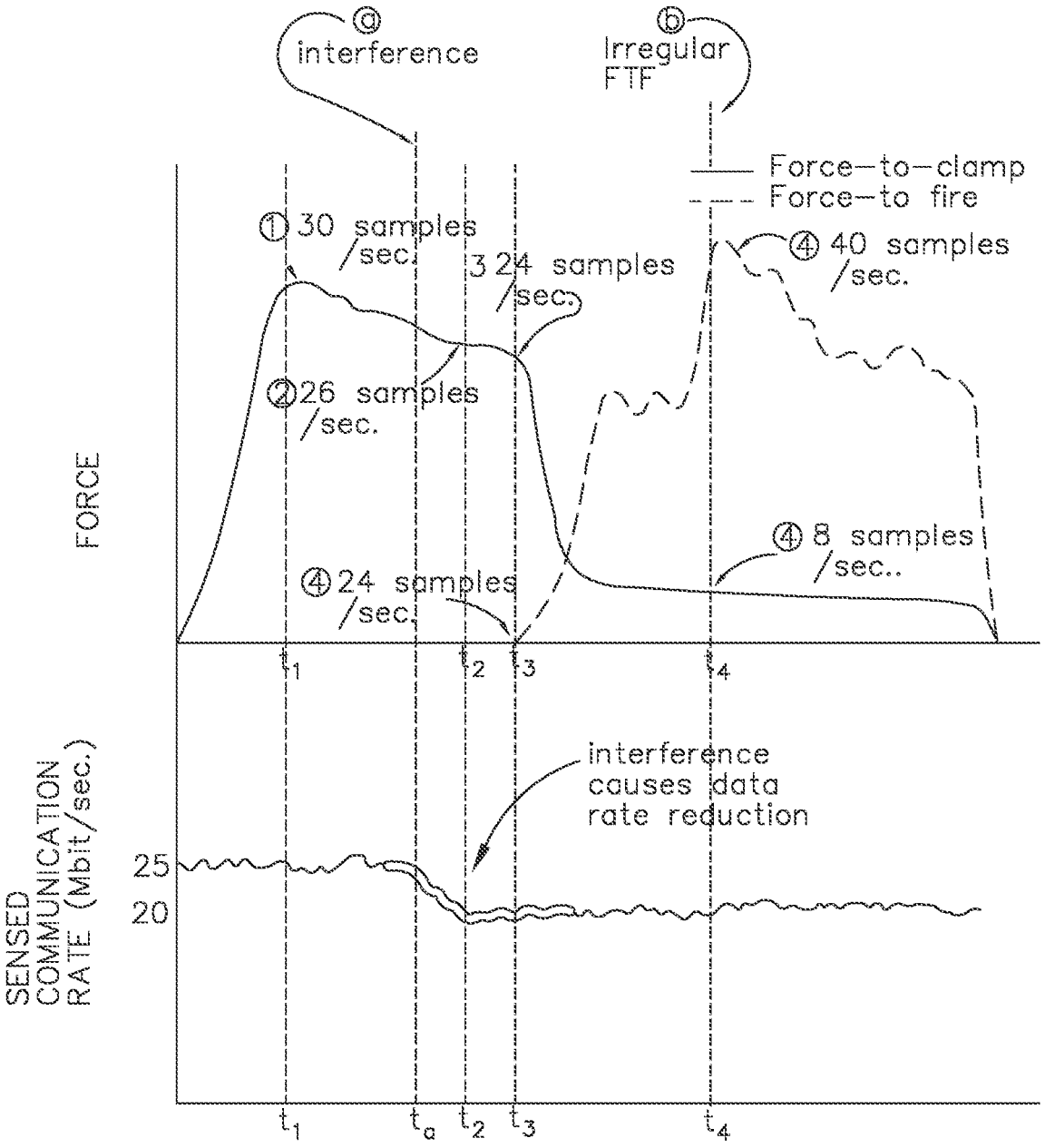
ⓐ interference
ⓑ Irregular FTF
Force—to—clamp
Force—to fire
① 30 samples /sec.
③ 24 samples /sec.
② 26 samples /sec.
④ 40 samples /sec.
④ 8 samples /sec..
④ 24 samples /sec.
FORCE
$t_1$
$t_2$
$t_3$
$t_4$
interference causes data rate reduction
SENSED COMMUNICATION RATE (Mbit/sec.)
25
20
$t_1$
$t_a$
$t_2$
$t_3$
$t_4$

FIG. 46

| | Mbit /sec | # of data feeds | Max. samples /sec. | Acturel Samples/sec. due to priortized feeds |
|---|---|---|---|---|
| (1) | 25 | 1 | 62 | FTC= 30<br>FTF= 0 |
| (2) | 20 | 1 | 62 | FTC= 26<br>FTF= 0 |
| (3) | 20 | 2 | 48 | FTC= 24<br>FTF= 24 |
| (4) | 20 | 2 | 48 | FTC= 8<br>FTF= 40 |

FIG. 47

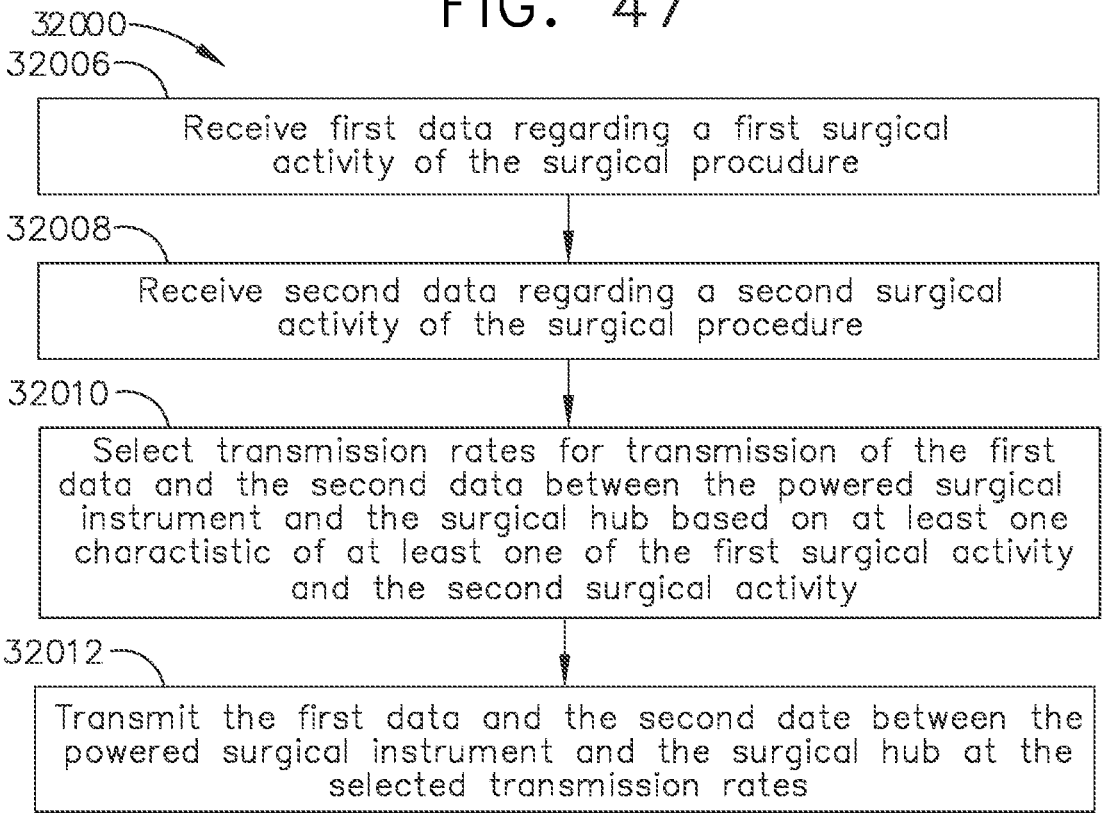


FIG. 48

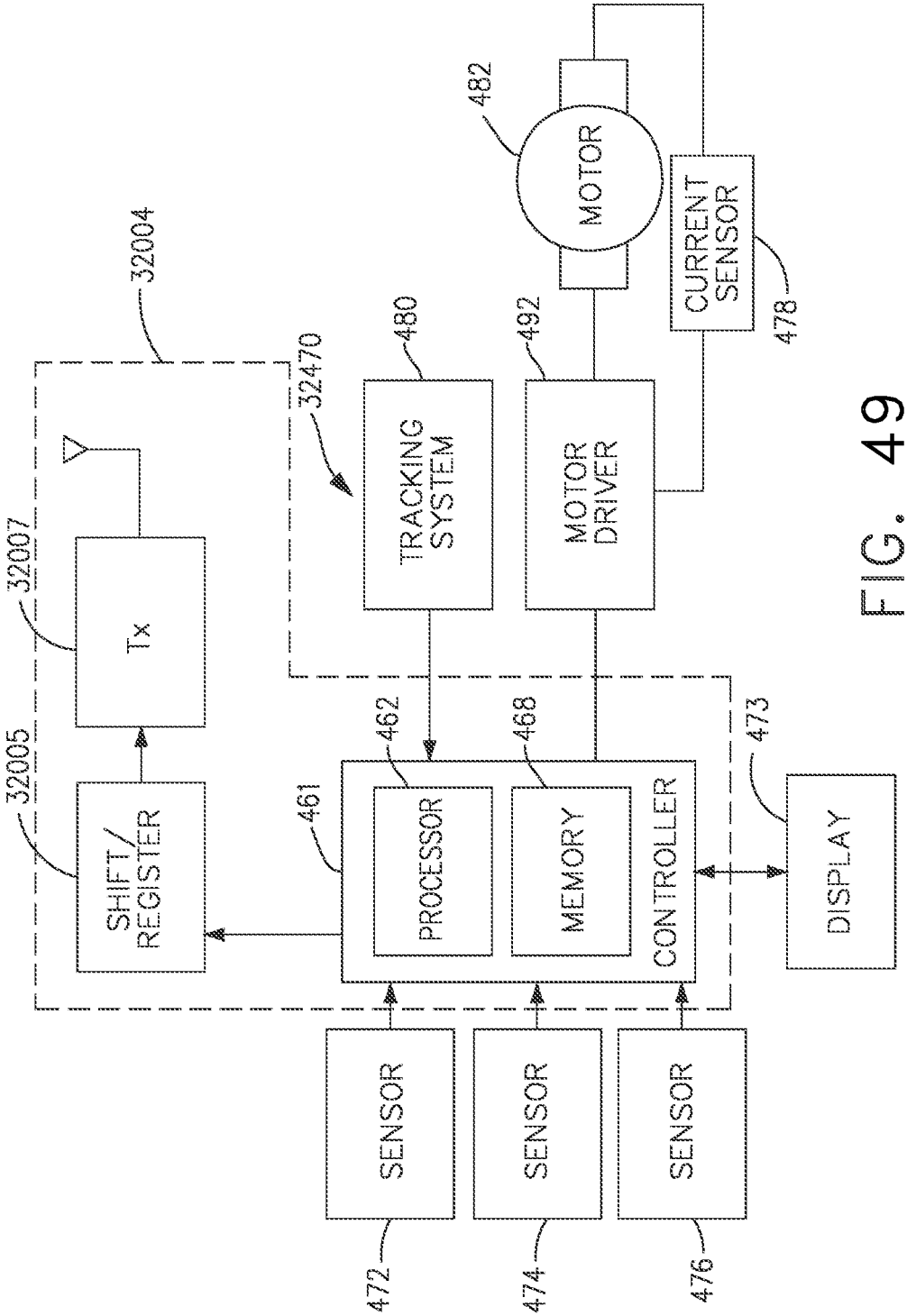
32004
32007
Tx
32005
SHIFT/
REGISTER
32470
TRACKING
SYSTEM
480
MOTOR
DRIVER
492
482
MOTOR
CURRENT
SENSOR
478
461
462
PROCESSOR
468
MEMORY
CONTROLLER
473
DISPLAY
SENSOR
SENSOR
SENSOR
472
474
476

FIG. 49

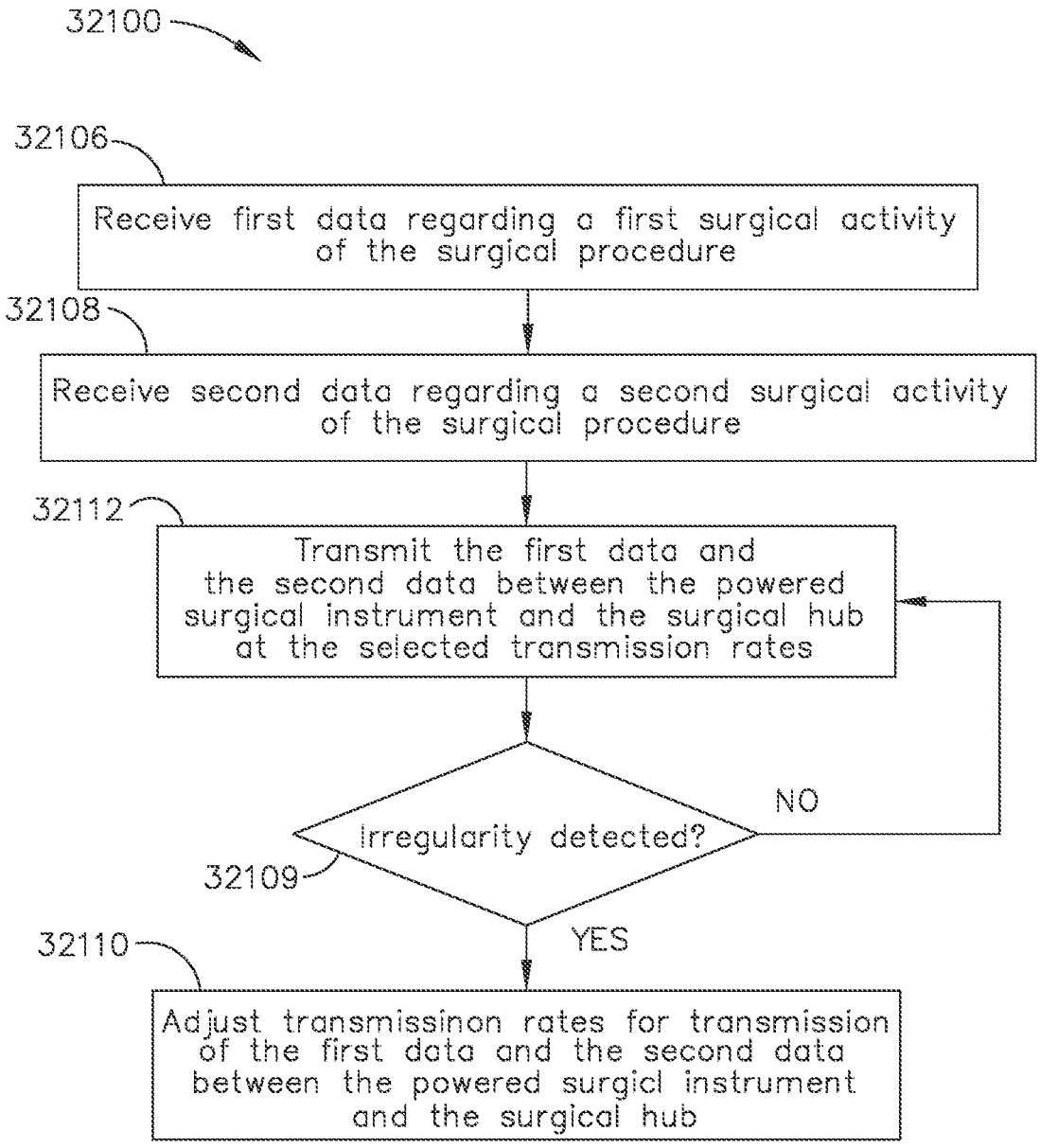
32100
32106
Receive first data regarding a first surgical activity of the surgical procedure
32108
Receive second data regarding a second surgical activity of the surgical procedure
32112
Transmit the first data and the second data between the powered surgical instrument and the surgical hub at the selected transmission rates
Irregularity detected?
NO
32109
YES
32110
Adjust transmissinon rates for transmission of the first data and the second data between the powered surgicl instrument and the surgical hub

FIG. 50

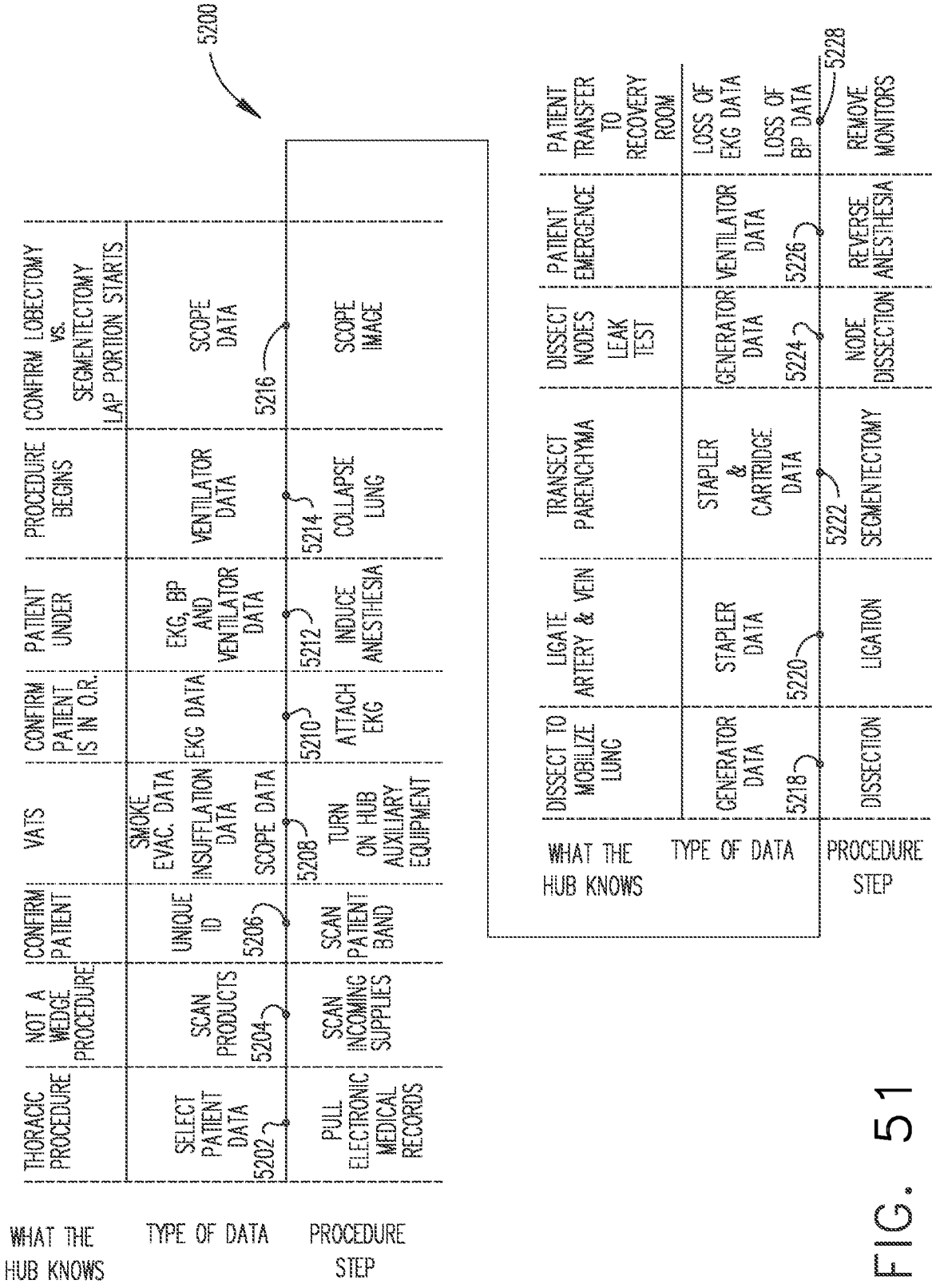
5200
WHAT THE HUB KNOWS
TYPE OF DATA
PROCEDURE STEP
THORACIC PROCEDURE
NOT A WEDGE PROCEDURE
CONFIRM PATIENT
VATS
CONFIRM PATIENT IS IN O.R.
PATIENT UNDER
PROCEDURE BEGINS
CONFIRM LOBECTOMY vs. SEGMENTECTOMY
LAP PORTION STARTS
SELECT PATIENT DATA
5202
SCAN PRODUCTS
5204
UNIQUE ID
5206
SMOKE EVAC. DATA
INSUFFLATION DATA
SCOPE DATA
5208
EKG DATA
EKG, BP AND VENTILATOR DATA
VENTILATOR DATA
5216
SCOPE DATA
PULL ELECTRONIC MEDICAL RECORDS
SCAN INCOMING SUPPLIES
SCAN PATIENT BAND
TURN ON HUB AUXILIARY EQUIPMENT
5210
ATTACH EKG
5212
INDUCE ANESTHESIA
5214
COLLAPSE LUNG
SCOPE IMAGE
DISSECT TO MOBILIZE LUNG
LIGATE ARTERY & VEIN
TRANSECT PARENCHYMA
DISSECT NODES
LEAK TEST
PATIENT EMERGENCE
PATIENT TRANSFER TO RECOVERY ROOM
GENERATOR DATA
5218
STAPLER DATA
5220
STAPLER & CARTRIDGE DATA
5222
GENERATOR DATA
5224
VENTILATOR DATA
5226
LOSS OF EKG DATA
LOSS OF BP DATA
5228
DISSECTION
LIGATION
SEGMENTECTOMY
NODE DISSECTION
REVERSE ANESTHESIA
REMOVE MONITORS

FIG. 51

# METHOD OF USING REINFORCED FLEXIBLE CIRCUITS WITH MULTIPLE SENSORS TO OPTIMIZE PERFORMANCE OF RADIO FREQUENCY DEVICES

## CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation application claiming priority 35 U.S.C. § 120 to U.S. patent application Ser. No. 17/825,754, titled METHOD OF USING REINFORCED FLEXIBLE CIRCUITS WITH MULTIPLE SENSORS TO OPTIMIZE PERFORMANCE OF RADIO FREQUENCY DEVICES, filed on May 26, 2022, which issued on Oct. 10, 2023 as U.S. Pat. No. 11,779,337 and which is a continuation application claiming priority under 35 U.S.C. § 120 to U.S. patent application Ser. No. 16/209,427, titled METHOD OF USING REINFORCED FLEXIBLE CIRCUITS WITH MULTIPLE SENSORS TO OPTIMIZE PERFORMANCE OF RADIO FREQUENCY DEVICES, filed on Dec. 4, 2018, which issued on Jul. 19, 2022 as U.S. Pat. No. 11,389,165 and which claims priority under 35 U.S.C. § 119(e) to each of the following: U.S. Provisional Patent Application No. 62/773,778, titled METHOD FOR ADAPTIVE CONTROL SCHEMES FOR SURGICAL NETWORK CONTROL AND INTERACTION, filed on Nov. 30, 2018; U.S. Provisional Patent Application No. 62/773,728, titled METHOD FOR SITUATIONAL AWARENESS FOR SURGICAL NETWORK OR SURGICAL NETWORK CONNECTED DEVICE CAPABLE OF ADJUSTING FUNCTION BASED ON A SENSED SITUATION OR USAGE, filed on Nov. 30, 2018; U.S. Provisional Patent Application No. 62/773,741, titled METHOD FOR FACILITY DATA COLLECTION AND INTERPRETATION, filed on Nov. 30, 2018; U.S. Provisional Patent Application No. 62/773,742, titled METHOD FOR CIRCULAR STAPLER CONTROL ALGORITHM ADJUSTMENT BASED ON SITUATIONAL AWARENESS, filed on Nov. 30, 2018; U.S. Provisional Patent Application No. 62/750,529, titled METHOD FOR OPERATING A POWERED ARTICULATING MULTI-CLIP APPLIER, filed on Oct. 25, 2018; U.S. Provisional Patent Application No. 62/750,539, titled SURGICAL CLIP APPLIER, filed on Oct. 25, 2018; U.S. Provisional Patent Application No. 62/750,555, titled SURGICAL CLIP APPLIER, filed on Oct. 25, 2018; U.S. Provisional Patent Application No. 62/729,183, titled CONTROL FOR A SURGICAL NETWORK OR SURGICAL NETWORK CONNECTED DEVICE THAT ADJUSTS ITS FUNCTION BASED ON A SENSED SITUATION OR USAGE, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,177, titled AUTOMATED DATA SCALING, ALIGNMENT, AND ORGANIZING BASED ON PREDEFINED PARAMETERS WITHIN A SURGICAL NETWORK BEFORE TRANSMISSION, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,176, titled INDIRECT COMMAND AND CONTROL OF A FIRST OPERATING ROOM SYSTEM THROUGH THE USE OF A SECOND OPERATING ROOM SYSTEM WITHIN A STERILE FIELD WHERE THE SECOND OPERATING ROOM SYSTEM HAS PRIMARY AND SECONDARY OPERATING MODES, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,185, titled POWERED STAPLING DEVICE THAT IS CAPABLE OF ADJUSTING FORCE, ADVANCEMENT SPEED, AND OVERALL STROKE OF CUTTING MEMBER OF THE DEVICE BASED ON SENSED PARAMETER OF FIRING OR CLAMPING, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,184, titled POWERED SURGICAL TOOL WITH A PREDEFINED ADJUSTABLE CONTROL ALGORITHM FOR CONTROLLING AT LEAST ONE END EFFECTOR PARAMETER AND A MEANS FOR LIMITING THE ADJUSTMENT, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,182, titled SENSING THE PATIENT POSITION AND CONTACT UTILIZING THE MONO-POLAR RETURN PAD ELECTRODE TO PROVIDE SITUATIONAL AWARENESS TO THE HUB, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,191, titled SURGICAL NETWORK RECOMMENDATIONS FROM REAL TIME ANALYSIS OF PROCEDURE VARIABLES AGAINST A BASELINE HIGHLIGHTING DIFFERENCES FROM THE OPTIMAL SOLUTION, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,195, titled ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/729,186, titled WIRELESS PAIRING OF A SURGICAL DEVICE WITH ANOTHER DEVICE WITHIN A STERILE SURGICAL FIELD BASED ON THE USAGE AND SITUATIONAL AWARENESS OF DEVICES, filed on Sep. 10, 2018; U.S. Provisional Patent Application No. 62/721,995, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION, filed on Aug. 23, 2018; U.S. Provisional Patent Application No. 62/721,998, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS, filed on Aug. 23, 2018; U.S. Provisional Patent Application No. 62/721,999, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING, filed on Aug. 23, 2018; U.S. Provisional Patent Application No. 62/721,994, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY, filed on Aug. 23, 2018; U.S. Provisional Patent Application No. 62/721,996, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS, filed on Aug. 23, 2018; U.S. Provisional Patent Application No. 62/692,747, titled SMART ACTIVATION OF AN ENERGY DEVICE BY ANOTHER DEVICE, filed on Jun. 30, 2018; U.S. Provisional Patent Application No. 62/692,748, titled SMART ENERGY ARCHITECTURE, filed on Jun. 30, 2018; U.S. Provisional Patent Application No. 62/692,768, titled SMART ENERGY DEVICES, filed on Jun. 30, 2018; U.S. Provisional Patent Application No. 62/691,228, titled METHOD OF USING REINFORCED FLEX CIRCUITS WITH MULTIPLE SENSORS WITH ELECTROSURGICAL DEVICES, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/691,227, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/691,230, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/691,219, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/691,257, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/691,262, titled SURGICAL EVACUATION SYSTEM

WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/691,251, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS, filed on Jun. 28, 2018; U.S. Provisional Patent Application No. 62/665,129, titled SURGICAL SUTURING SYSTEMS, filed on May 1, 2018; U.S. Provisional Patent Application No. 62/665,139, titled SURGICAL INSTRUMENTS COMPRISING CONTROL SYSTEMS, filed on May 1, 2018; U.S. Provisional Patent Application No. 62/665,177, titled SURGICAL INSTRUMENTS COMPRISING HANDLE ARRANGEMENTS, filed on May 1, 2018; U.S. Provisional Patent Application No. 62/665,128, titled MODULAR SURGICAL INSTRUMENTS, filed on May 1, 2018; U.S. Provisional Patent Application No. 62/665,192, titled SURGICAL DISSECTORS, filed on May 1, 2018; U.S. Provisional Patent Application No. 62/665,134, titled SURGICAL CLIP APPLIER, filed on May 1, 2018; U.S. Provisional Patent Application No. 62/659,900, titled METHOD OF HUB COMMUNICATION, filed on Apr. 19, 2018; U.S. Provisional Patent Application No. 62/650,898, filed on Mar. 30, 2018, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS, U.S. Provisional Patent Application No. 62/650,887, titled SURGICAL SYSTEMS WITH OPTIMIZED SENSING CAPABILITIES, filed on Mar. 30, 2018; U.S. Provisional Patent Application No. 62/650,882, titled SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM, filed on Mar. 30, 2018; U.S. Provisional Patent Application No. 62/650,877, titled SURGICAL SMOKE EVACUATION SENSING AND CONTROLS, filed on Mar. 30, 2018; U.S. Provisional Patent Application No. 62/649,302, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,294, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,300, titled SURGICAL HUB SITUATIONAL AWARENESS, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,309, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,310, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,291, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,296, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,333, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,327, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,315, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,313, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,320, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,307, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/649,323, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS, filed on Mar. 28, 2018; U.S. Provisional Patent Application No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed on Dec. 28, 2017; U.S. Provisional Patent Application No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed on Dec. 28, 2017; U.S. Provisional Patent Application No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed on Dec. 28, 2017, the disclosure of each of which is herein incorporated by reference in their entireties.

## BACKGROUND

This application discloses an invention that is related, generally and in various aspects, to surgical systems, surgical instruments, and flexible circuits.

Surgical instruments include components that are required to move in various directions and/or are subjected to different forces. For example, shafts rotate, articulate, and experience different tensions; jaws pivot open and closed and experience unwanted flexing or deformation; and cutting members move axially in distal and proximal directions and experience different resistive forces.

Surgical instruments may also include additional components such as electrodes, sensing devices, processing circuits, motors, and wiring and/or wiring traces, some of which can be located within various portions of a surgical instrument. For example, a sensing device and/or a processing circuit can be located within an end effector of the surgical instrument, within a shaft assembly of the surgical instrument and/or within a handle assembly of the surgical instrument. Such additional components can form electrical circuits of the surgical instrument, and portions of such electrical circuits can also be required to move in various directions and/or be subjected to different forces.

In many instances, the jaw electrodes of various surgical instruments are rigid, are utilized as therapeutic electrodes that apply electrosurgical energy to tissue positioned between the jaws, collectively take up close to an entire width of the jaws, and can experience flexing or deformation as the jaws open and close. For surgical instruments that include a knife that traverses a slot defined by the jaws, a first electrode can be positioned to a first side (e.g., a right hand side) of the slot and a second electrode can be positioned to a second side (e.g., a left hand side) of the slot.

Due to their rigid nature, the unwanted flexing or deformation of the electrodes can lead to premature failure. Also, by collectively taking up close to an entire width of the jaws, the electrodes have a relatively large surface area that is in contact with tissue positioned between the jaws. When the electrodes deliver radio-frequency (RF) energy to the tissue, the large surface area of the electrodes can contribute to unwanted tissue sticking. Additionally, the large surface area of the electrodes leaves little room for sensing and/or measurement devices to have contact with tissue positioned between the jaws.

With traditional electrical circuits in surgical instruments, portions of the electrical circuits which are required to move in various directions and/or be subjected to different forces

tend to pull out or separate from their connection to the surgical instrument and/or fail at a rate which is higher than desired.

## SUMMARY

In one aspect the present disclosure provides a method implemented by a surgical instrument. The surgical instrument comprising first and second jaws and a flexible circuit comprising multiple sensors to optimize performance of a radio frequency (RF) device. The flexible circuit comprising at least one therapeutic electrode couplable to a source of RF energy, at least two sensing electrodes, and at least one insulative layer. The insulative layer is positioned between the at least one therapeutic electrode and the at least two sensing electrodes. The method comprising: contacting tissue positioned between the first and second jaws of the surgical instrument with the at least one therapeutic electrode and at the least two sensing electrodes; sensing signals from the at the least two sensing electrodes; and controlling RF energy delivered to the at least one therapeutic electrode based on the sensed signals.

In another aspect the present disclosure provides a method implemented by a surgical instrument comprising an end effector, a marking assembly, and a control circuit. The end effector comprising a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, a plurality of sensors, and a tissue-treatment mechanism configured to apply a tissue treatment to tissue grasped between the first jaw and the second jaw. The method comprising: receiving, by the control circuit, a plurality of sensor signals from the plurality of sensors indicative of application of a tissue treatment to the tissue; controlling, by the control circuit, radiofrequency (RF) energy to the end effector to treat the tissue; applying, by the marking assembly, a distinct marking to the tissue unique to the tissue treatment application, wherein the distinct marking distinguishes the tissue treatment application from other tissue treatment applications.

In another aspect the present disclosure provides a method implemented by a surgical instrument. The surgical instrument comprising a control circuit, a multi-level flexible electrode. The multi-level flexible electrode comprises first, second, and third insulative layers. The multi-level flexible electrode further comprises at least one therapeutic electrode and at least two sensing electrodes. The therapeutic electrode is positioned between the first and second insulative layers. The therapeutic electrode is couplable to a source of radiofrequency (RF) energy. The sensing electrode is positioned between the second and third insulative layers. The method comprising: contacting tissue by the at least one therapeutic electrode and the at least two sensing electrodes; delivering RF energy to the contacted tissue by the at least one therapeutic electrode; sensing, by the at least two sensing electrodes, a parameter associated with tissue positioned between first and second jaws of the surgical instrument; and controlling, by the control circuit, RF energy delivered to the at least one therapeutic electrode based on the sensed parameter.

## BRIEF DESCRIPTION

The features of various aspects are set forth with particularity in the appended claims. The various aspects, however, both as to organization and methods of operation, together with further objects and advantages thereof, may best be understood by reference to the following description, taken in conjunction with the accompanying drawings as follows.

FIG. **1** is a block diagram of a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **2** is a surgical system being used to perform a surgical procedure in an operating room, in accordance with at least one aspect of the present disclosure.

FIG. **3** is a surgical hub paired with a visualization system, a robotic system, and an intelligent instrument, in accordance with at least one aspect of the present disclosure.

FIG. **4** is a partial perspective view of a surgical hub enclosure and of a combo generator module slidably receivable in a drawer of the surgical hub enclosure, in accordance with at least one aspect of the present disclosure.

FIG. **5** is a perspective view of a combo generator module with bipolar, ultrasonic, and monopolar contacts and a smoke evacuation component, in accordance with at least one aspect of the present disclosure.

FIG. **6** illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

FIG. **7** illustrates a vertical modular housing configured to receive a plurality of modules, in accordance with at least one aspect of the present disclosure.

FIG. **8** illustrates a surgical data network comprising a modular communication hub configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to the cloud, in accordance with at least one aspect of the present disclosure.

FIG. **9** illustrates a computer-implemented interactive surgical system, in accordance with at least one aspect of the present disclosure.

FIG. **10** illustrates a surgical hub comprising a plurality of modules coupled to the modular control tower, in accordance with at least one aspect of the present disclosure.

FIG. **11** illustrates one aspect of a Universal Serial Bus (USB) network hub device, in accordance with at least one aspect of the present disclosure.

FIG. **12** illustrates a logic diagram of a control system of a surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **13** illustrates a control circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **14** illustrates a combinational logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **15** illustrates a sequential logic circuit configured to control aspects of the surgical instrument or tool, in accordance with at least one aspect of the present disclosure.

FIG. **16** illustrates a surgical instrument or tool comprising a plurality of motors that can be activated to perform various functions, in accordance with at least one aspect of the present disclosure.

FIG. **17** is a schematic diagram of a robotic surgical instrument configured to operate a surgical tool described herein, in accordance with at least one aspect of the present disclosure.

FIG. **18** illustrates a block diagram of a surgical instrument programmed to control the distal translation of a displacement member, in accordance with at least one aspect of the present disclosure.

FIG. **19** is a schematic diagram of a surgical instrument configured to control various functions, in accordance with at least one aspect of the present disclosure.

FIG. **20** is a simplified block diagram of a generator configured to provide inductorless tuning, among other benefits, in accordance with at least one aspect of the present disclosure.

FIG. **21** illustrates an example of a generator, which is one form of the generator of FIG. **20**, in accordance with at least one aspect of the present disclosure.

FIG. **22** illustrates a surgical instrument, in accordance with at least one aspect of the present disclosure.

FIG. **23** illustrates a shaft assembly of the surgical instrument of FIG. **22**, in accordance with at least one other aspect of the present disclosure.

FIG. **24** illustrates a flexible circuit of the surgical instrument of FIG. **22**, in accordance with at least one aspect of the present disclosure.

FIG. **25** illustrates a channel retainer of the surgical instrument of FIG. **22**, in accordance with at least one aspect of the present disclosure.

FIG. **26** illustrates a cross-section of the flexible circuit along the line A-A of FIG. **24**, in accordance with at least one aspect of the present disclosure.

FIG. **27** illustrates a cross-section of the flexible circuit along the line B-B of FIG. **24**, in accordance with at least one aspect of the present disclosure.

FIG. **28** illustrates an exploded view of a flexible electrode of the surgical instrument of FIG. **22**, in accordance with at least one aspect of the present disclosure.

FIGS. **29** and **30** illustrate top views of a flexible electrode of the surgical instrument of FIG. **22**, in accordance with at least one aspect of the present disclosure.

FIG. **31** illustrates an exploded view of a flexible electrode of the surgical instrument of FIG. **22**, in accordance with at least one other aspect of the present disclosure.

FIG. **32** illustrates an end view of a flexible electrode of the surgical instrument of FIG. **22**, in accordance with at least one other aspect of the present disclosure.

FIG. **33** illustrates a top perspective view of a flexible electrode of the surgical instrument of FIG. **22**, in accordance with at least one other aspect of the present disclosure.

FIG. **34** is a perspective view of a surgical instrument that has an interchangeable shaft assembly operably coupled thereto, in accordance with at least one aspect of the present disclosure.

FIG. **35** is an exploded assembly view of a portion of the surgical instrument of FIG. **34**, in accordance with at least one aspect of the present disclosure.

FIG. **36** is an exploded assembly view of portions of the interchangeable shaft assembly, in accordance with at least one aspect of the present disclosure.

FIG. **37** is an exploded view of an end effector of the surgical instrument of FIG. **34**, in accordance with at least one aspect of the present disclosure.

FIG. **38**A is a block diagram of a control circuit of the surgical instrument of FIG. **34** spanning two drawing sheets, in accordance with at least one aspect of the present disclosure.

FIG. **38**B is a block diagram of a control circuit of the surgical instrument of FIG. **34** spanning two drawing sheets, in accordance with at least one aspect of the present disclosure.

FIG. **39** is a block diagram of the control circuit of the surgical instrument of FIG. **34** illustrating interfaces between the handle assembly, the power assembly, and the handle assembly and the interchangeable shaft assembly, in accordance with at least one aspect of the present disclosure.

FIG. **40** illustrates a logic flow diagram of a process depicting a control program or a logic configuration for marking tissue, in accordance with at least one aspect of the present disclosure.

FIG. **41** illustrates a jaw member of an end effector that includes a staple cartridge, in accordance with at least one aspect of the present disclosure.

FIG. **42** illustrates a jaw member of an end effector of an ultrasonic surgical instrument, in accordance with at least one aspect of the present disclosure.

FIG. **43** illustrates an end effector of a surgical stapling and cutting instrument, in accordance with at least one aspect of the present disclosure.

FIG. **44** illustrates a control system of a surgical instrument, in accordance with at least one aspect of the present disclosure.

FIG. **45** illustrates tissue treatments applied to tissue to remove a cancerous portion of a colon, in accordance with at least one aspect of the present disclosure.

FIG. **46** is a graph illustrating force-to-clamp (FTC) and force-to-fire (FTF) readings for a powered surgical instrument during a surgical procedure, and corresponding communication rates of transmission of the readings to a surgical hub, the readings and the communication rates being plotted against time, in accordance with at least one aspect of the present disclosure.

FIG. **47** illustrates transmission rates for FTC data and FTF data at four example points in the graph of FIG. **46**, in accordance with at least one aspect of the present disclosure.

FIG. **48** illustrates a logic flow diagram of a process depicting a control program or a logic configuration for coordinating transmission of data between a powered surgical instrument and a surgical hub, in accordance with at least one aspect of the present disclosure.

FIG. **49** is a control system of the powered surgical instrument of FIG. **46**, in accordance with at least one aspect of the present disclosure.

FIG. **50** illustrates a logic flow diagram of a process depicting a control program or a logic configuration for coordinating transmission of data between a powered surgical instrument and a surgical hub, in accordance with at least one aspect of the present disclosure.

FIG. **51** is a timeline depicting situational awareness of a surgical hub, in accordance with at least one aspect of the present disclosure.

## DESCRIPTION

Applicant of the present application owns the following U.S. patent applications, filed on Dec. 4, 2018, the disclosures of each of which are herein incorporated by reference in their entireties:

- application Ser. No. 16/209,385, titled METHOD OF HUB COMMUNICATION, PROCESSING, STORAGE AND DISPLAY, now U.S. Patent Application Publication No. 2019/0200844;
- application Ser. No. 16/209,395, titled METHOD OF HUB COMMUNICATION, now U.S. Patent Application Publication No. 2019/0201136;
- Application Ser. No. 16/209,403, titled METHOD OF CLOUD BASED DATA ANALYTICS FOR USE WITH THE HUB, now U.S. Patent Application Publication No. 2019/0206569;

application Ser. No. 16/209,407, titled METHOD OF ROBOTIC HUB COMMUNICATION, DETECTION, AND CONTROL, now U.S. Patent Application Publication No. 2019/0201137;

application Ser. No. 16/209,416, titled METHOD OF HUB COMMUNICATION, PROCESSING, DISPLAY, AND CLOUD ANALYTICS, now U.S. Patent Application Publication No. 2019/0206562;

application Ser. No. 16/209,423, titled METHOD OF COMPRESSING TISSUE WITHIN A STAPLING DEVICE AND SIMULTANEOUSLY DISPLAYING THE LOCATION OF THE TISSUE WITHIN THE JAWS, now U.S. Patent Application Publication No. 2019/0200981;

application Ser. No. 16/209,433, titled METHOD OF SENSING PARTICULATE FROM SMOKE EVACUATED FROM A PATIENT, ADJUSTING THE PUMP SPEED BASED ON THE SENSED INFORMATION, AND COMMUNICATING THE FUNCTIONAL PARAMETERS OF THE SYSTEM TO THE HUB, now U.S. Patent Application Publication No. 2019/0201594;

application Ser. No. 16/209,447, titled METHOD FOR SMOKE EVACUATION FOR SURGICAL HUB, now U.S. Patent Application Publication No. 2019/0201045;

application Ser. No. 16/209,453, titled METHOD FOR CONTROLLING SMART ENERGY DEVICES, now U.S. Patent Application Publication No. 2019/0201046;

application Ser. No. 16/209,458, titled METHOD FOR SMART ENERGY DEVICE INFRASTRUCTURE, now U.S. Patent Application Publication No. 2019/0201047;

application Ser. No. 16/209,465, titled METHOD FOR ADAPTIVE CONTROL SCHEMES FOR SURGICAL NETWORK CONTROL AND INTERACTION, now U.S. Pat. No. 11,304,699;

application Ser. No. 16/209,478, titled METHOD FOR SITUATIONAL AWARENESS FOR SURGICAL NETWORK OR SURGICAL NETWORK CONNECTED DEVICE CAPABLE OF ADJUSTING FUNCTION BASED ON A SENSED SITUATION OR USAGE, now U.S. Patent Application Publication No. 2019/0104919;

application Ser. No. 16/209,490, titled METHOD FOR FACILITY DATA COLLECTION AND INTERPRETATION, now U.S. Patent Application Publication No. 2019/0206564; and

application Ser. No. 16/209,491, titled METHOD FOR CIRCULAR STAPLER CONTROL ALGORITHM ADJUSTMENT BASED ON SITUATIONAL AWARENESS, now U.S. Pat. No. 11,109,866.

Applicant of the present application owns the following U.S. patent applications, filed on Nov. 6, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

U.S. patent application Ser. No. 16/182,224, titled SURGICAL NETWORK, INSTRUMENT, AND CLOUD RESPONSES BASED ON VALIDATION OF RECEIVED DATASET AND AUTHENTICATION OF ITS SOURCE AND INTEGRITY;

U.S. patent application Ser. No. 16/182,230, titled SURGICAL SYSTEM FOR PRESENTING INFORMATION INTERPRETED FROM EXTERNAL DATA;

U.S. patent application Ser. No. 16/182,233, titled SURGICAL SYSTEMS WITH AUTONOMOUSLY ADJUSTABLE CONTROL PROGRAMS;

U.S. patent application Ser. No. 16/182,239, titled ADJUSTMENT OF DEVICE CONTROL PROGRAMS BASED ON STRATIFIED CONTEXTUAL DATA IN ADDITION TO THE DATA;

U.S. patent application Ser. No. 16/182,243, titled SURGICAL HUB AND MODULAR DEVICE RESPONSE ADJUSTMENT BASED ON SITUATIONAL AWARENESS;

U.S. patent application Ser. No. 16/182,248, titled DETECTION AND ESCALATION OF SECURITY RESPONSES OF SURGICAL INSTRUMENTS TO INCREASING SEVERITY THREATS;

U.S. patent application Ser. No. 16/182,251, titled INTERACTIVE SURGICAL SYSTEM;

U.S. patent application Ser. No. 16/182,260, titled AUTOMATED DATA SCALING, ALIGNMENT, AND ORGANIZING BASED ON PREDEFINED PARAMETERS WITHIN SURGICAL NETWORKS;

U.S. patent application Ser. No. 16/182,267, titled SENSING THE PATIENT POSITION AND CONTACT UTILIZING THE MONO-POLAR RETURN PAD ELECTRODE TO PROVIDE SITUATIONAL AWARENESS TO THE HUB;

U.S. patent application Ser. No. 16/182,249, titled POWERED SURGICAL TOOL WITH PREDEFINED ADJUSTABLE CONTROL ALGORITHM FOR CONTROLLING END EFFECTOR PARAMETER;

U.S. patent application Ser. No. 16/182,246, titled ADJUSTMENTS BASED ON AIRBORNE PARTICLE PROPERTIES;

U.S. patent application Ser. No. 16/182,256, titled ADJUSTMENT OF A SURGICAL DEVICE FUNCTION BASED ON SITUATIONAL AWARENESS;

U.S. patent application Ser. No. 16/182,242, titled REAL-TIME ANALYSIS OF COMPREHENSIVE COST OF ALL INSTRUMENTATION USED IN SURGERY UTILIZING DATA FLUIDITY TO TRACK INSTRUMENTS THROUGH STOCKING AND IN-HOUSE PROCESSES;

U.S. patent application Ser. No. 16/182,255, titled USAGE AND TECHNIQUE ANALYSIS OF SURGEON/STAFF PERFORMANCE AGAINST A BASELINE TO OPTIMIZE DEVICE UTILIZATION AND PERFORMANCE FOR BOTH CURRENT AND FUTURE PROCEDURES;

U.S. patent application Ser. No. 16/182,269, titled IMAGE CAPTURING OF THE AREAS OUTSIDE THE ABDOMEN TO IMPROVE PLACEMENT AND CONTROL OF A SURGICAL DEVICE IN USE;

U.S. patent application Ser. No. 16/182,278, titled COMMUNICATION OF DATA WHERE A SURGICAL NETWORK IS USING CONTEXT OF THE DATA AND REQUIREMENTS OF A RECEIVING SYSTEM/USER TO INFLUENCE INCLUSION OR LINKAGE OF DATA AND METADATA TO ESTABLISH CONTINUITY;

U.S. patent application Ser. No. 16/182,290, titled SURGICAL NETWORK RECOMMENDATIONS FROM REAL TIME ANALYSIS OF PROCEDURE VARIABLES AGAINST A BASELINE HIGHLIGHTING DIFFERENCES FROM THE OPTIMAL SOLUTION;

U.S. patent application Ser. No. 16/182,232, titled CONTROL OF A SURGICAL SYSTEM THROUGH A SURGICAL BARRIER;

U.S. patent application Ser. No. 16/182,227, titled SURGICAL NETWORK DETERMINATION OF PRIORITIZATION OF COMMUNICATION, INTERACTION, OR PROCESSING BASED ON SYSTEM OR DEVICE NEEDS;

U.S. patent application Ser. No. 16/182,231, titled WIRELESS PAIRING OF A SURGICAL DEVICE WITH ANOTHER DEVICE WITHIN A STERILE SURGICAL FIELD BASED ON THE USAGE AND SITUATIONAL AWARENESS OF DEVICES;

U.S. patent application Ser. No. 16/182,229, titled ADJUSTMENT OF STAPLE HEIGHT OF AT LEAST ONE ROW OF STAPLES BASED ON THE SENSED TISSUE THICKNESS OR FORCE IN CLOSING;

U.S. patent application Ser. No. 16/182,234, titled STAPLING DEVICE WITH BOTH COMPULSORY AND DISCRETIONARY LOCKOUTS BASED ON SENSED PARAMETERS;

U.S. patent application Ser. No. 16/182,240, titled POWERED STAPLING DEVICE CONFIGURED TO ADJUST FORCE, ADVANCEMENT SPEED, AND OVERALL STROKE OF CUTTING MEMBER BASED ON SENSED PARAMETER OF FIRING OR CLAMPING;

U.S. patent application Ser. No. 16/182,235, titled VARIATION OF RADIO FREQUENCY AND ULTRASONIC POWER LEVEL IN COOPERATION WITH VARYING CLAMP ARM PRESSURE TO ACHIEVE PREDEFINED HEAT FLUX OR POWER APPLIED TO TISSUE; and

U.S. patent application Ser. No. 16/182,238, titled ULTRASONIC ENERGY DEVICE WHICH VARIES PRESSURE APPLIED BY CLAMP ARM TO PROVIDE THRESHOLD CONTROL PRESSURE AT A CUT PROGRESSION LOCATION.

Applicant of the present application owns the following U.S. patent applications that were filed on Oct. 26, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

U.S. patent application Ser. No. 16/172,303, titled METHOD FOR OPERATING A POWERED ARTICULATING MULTI-CLIP APPLIER;

U.S. patent application Ser. No. 16/172,130, titled CLIP APPLIER COMPRISING INTERCHANGEABLE CLIP RELOADS;

U.S. patent application Ser. No. 16/172,066, titled CLIP APPLIER COMPRISING A MOVABLE CLIP MAGAZINE;

U.S. patent application Ser. No. 16/172,078, titled CLIP APPLIER COMPRISING A ROTATABLE CLIP MAGAZINE;

U.S. patent application Ser. No. 16/172,087, titled CLIP APPLIER COMPRISING CLIP ADVANCING SYSTEMS;

U.S. patent application Ser. No. 16/172,094, titled CLIP APPLIER COMPRISING A CLIP CRIMPING SYSTEM;

U.S. patent application Ser. No. 16/172,128, titled CLIP APPLIER COMPRISING A RECIPROCATING CLIP ADVANCING MEMBER;

U.S. patent application Ser. No. 16/172,168, titled CLIP APPLIER COMPRISING A MOTOR CONTROLLER;

U.S. patent application Ser. No. 16/172,164, titled SURGICAL SYSTEM COMPRISING A SURGICAL TOOL AND A SURGICAL HUB;

U.S. patent application Ser. No. 16/172,328, titled METHOD OF HUB COMMUNICATION WITH SURGICAL INSTRUMENT SYSTEMS;

U.S. patent application Ser. No. 16/172,280, titled METHOD FOR PRODUCING A SURGICAL INSTRUMENT COMPRISING A SMART ELECTRICAL SYSTEM;

U.S. patent application Ser. No. 16/172,219, titled METHOD OF HUB COMMUNICATION WITH SURGICAL INSTRUMENT SYSTEMS;

U.S. patent application Ser. No. 16/172,248, titled METHOD OF HUB COMMUNICATION WITH SURGICAL INSTRUMENT SYSTEMS;

U.S. patent application Ser. No. 16/172,198, titled METHOD OF HUB COMMUNICATION WITH SURGICAL INSTRUMENT SYSTEMS; and

U.S. patent application Ser. No. 16/172,155, titled METHOD OF HUB COMMUNICATION WITH SURGICAL INSTRUMENT SYSTEMS.

Applicant of the present application owns the following U.S. patent applications, filed on Aug. 28, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

U.S. patent application Ser. No. 16/115,214, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR;

U.S. patent application Ser. No. 16/115,205, titled TEMPERATURE CONTROL OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR;

U.S. patent application Ser. No. 16/115,233, titled RADIO FREQUENCY ENERGY DEVICE FOR DELIVERING COMBINED ELECTRICAL SIGNALS;

U.S. patent application Ser. No. 16/115,208, titled CONTROLLING AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO TISSUE LOCATION;

U.S. patent application Ser. No. 16/115,220, titled CONTROLLING ACTIVATION OF AN ULTRASONIC SURGICAL INSTRUMENT ACCORDING TO THE PRESENCE OF TISSUE;

U.S. patent application Ser. No. 16/115,232, titled DETERMINING TISSUE COMPOSITION VIA AN ULTRASONIC SYSTEM;

U.S. patent application Ser. No. 16/115,239, titled DETERMINING THE STATE OF AN ULTRASONIC ELECTROMECHANICAL SYSTEM ACCORDING TO FREQUENCY SHIFT;

U.S. patent application Ser. No. 16/115,247, titled DETERMINING THE STATE OF AN ULTRASONIC END EFFECTOR;

U.S. patent application Ser. No. 16/115,211, titled SITUATIONAL AWARENESS OF ELECTROSURGICAL SYSTEMS;

U.S. patent application Ser. No. 16/115,226, titled MECHANISMS FOR CONTROLLING DIFFERENT ELECTROMECHANICAL SYSTEMS OF AN ELECTROSURGICAL INSTRUMENT;

U.S. patent application Ser. No. 16/115,240, titled DETECTION OF END EFFECTOR EMERSION IN LIQUID;

U.S. patent application Ser. No. 16/115,249, titled INTERRUPTION OF ENERGY DUE TO INADVERTENT CAPACITIVE COUPLING;

U.S. patent application Ser. No. 16/115,256, titled INCREASING RADIO FREQUENCY TO CREATE PAD-LESS MONOPOLAR LOOP;

U.S. patent application Ser. No. 16/115,223, titled BIPOLAR COMBINATION DEVICE THAT AUTOMATICALLY ADJUSTS PRESSURE BASED ON ENERGY MODALITY; and

U.S. patent application Ser. No. 16/115,238, titled ACTIVATION OF ENERGY DEVICES.

Applicant of the present application owns the following U.S. patent applications, filed on Aug. 24, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

U.S. patent application Ser. No. 16/112,129, titled SURGICAL SUTURING INSTRUMENT CONFIGURED TO MANIPULATE TISSUE USING MECHANICAL AND ELECTRICAL POWER;

U.S. patent application Ser. No. 16/112,155, titled SURGICAL SUTURING INSTRUMENT COMPRISING A CAPTURE WIDTH WHICH IS LARGER THAN TROCAR DIAMETER;

U.S. patent application Ser. No. 16/112,168, titled SURGICAL SUTURING INSTRUMENT COMPRISING A NON-CIRCULAR NEEDLE;

U.S. patent application Ser. No. 16/112,180, titled ELECTRICAL POWER OUTPUT CONTROL BASED ON MECHANICAL FORCES;

U.S. patent application Ser. No. 16/112,193, titled REACTIVE ALGORITHM FOR SURGICAL SYSTEM;

U.S. patent application Ser. No. 16/112,099, titled SURGICAL INSTRUMENT COMPRISING AN ADAPTIVE ELECTRICAL SYSTEM;

U.S. patent application Ser. No. 16/112,112, titled CONTROL SYSTEM ARRANGEMENTS FOR A MODULAR SURGICAL INSTRUMENT;

U.S. patent application Ser. No. 16/112,119, titled ADAPTIVE CONTROL PROGRAMS FOR A SURGICAL SYSTEM COMPRISING MORE THAN ONE TYPE OF CARTRIDGE;

U.S. patent application Ser. No. 16/112,097, titled SURGICAL INSTRUMENT SYSTEMS COMPRISING BATTERY ARRANGEMENTS;

U.S. patent application Ser. No. 16/112,109, titled SURGICAL INSTRUMENT SYSTEMS COMPRISING HANDLE ARRANGEMENTS;

U.S. patent application Ser. No. 16/112,114, titled SURGICAL INSTRUMENT SYSTEMS COMPRISING FEEDBACK MECHANISMS;

U.S. patent application Ser. No. 16/112,117, titled SURGICAL INSTRUMENT SYSTEMS COMPRISING LOCKOUT MECHANISMS;

U.S. patent application Ser. No. 16/112,095, titled SURGICAL INSTRUMENTS COMPRISING A LOCKABLE END EFFECTOR SOCKET;

U.S. patent application Ser. No. 16/112,121, titled SURGICAL INSTRUMENTS COMPRISING A SHIFTING MECHANISM;

U.S. patent application Ser. No. 16/112,151, titled SURGICAL INSTRUMENTS COMPRISING A SYSTEM FOR ARTICULATION AND ROTATION COMPENSATION;

U.S. patent application Ser. No. 16/112,154, titled SURGICAL INSTRUMENTS COMPRISING A BIASED SHIFTING MECHANISM;

U.S. patent application Ser. No. 16/112,226, titled SURGICAL INSTRUMENTS COMPRISING AN ARTICULATION DRIVE THAT PROVIDES FOR HIGH ARTICULATION ANGLES;

U.S. patent application Ser. No. 16/112,062, titled SURGICAL DISSECTORS AND MANUFACTURING TECHNIQUES;

U.S. patent application Ser. No. 16/112,098, titled SURGICAL DISSECTORS CONFIGURED TO APPLY MECHANICAL AND ELECTRICAL ENERGY;

U.S. patent application Ser. No. 16/112,237, titled SURGICAL CLIP APPLIER CONFIGURED TO STORE CLIPS IN A STORED STATE;

U.S. patent application Ser. No. 16/112,245, titled SURGICAL CLIP APPLIER COMPRISING AN EMPTY CLIP CARTRIDGE LOCKOUT;

U.S. patent application Ser. No. 16/112,249, titled SURGICAL CLIP APPLIER COMPRISING AN AUTOMATIC CLIP FEEDING SYSTEM;

U.S. patent application Ser. No. 16/112,253, titled SURGICAL CLIP APPLIER COMPRISING ADAPTIVE FIRING CONTROL; and

U.S. patent application Ser. No. 16/112,257, titled SURGICAL CLIP APPLIER COMPRISING ADAPTIVE CONTROL IN RESPONSE TO A STRAIN GAUGE CIRCUIT.

Applicant of the present application owns the following U.S. patent applications, filed on Jun. 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

U.S. patent application Ser. No. 16/024,090, titled CAPACITIVE COUPLED RETURN PATH PAD WITH SEPARABLE ARRAY ELEMENTS;

U.S. patent application Ser. No. 16/024,057, titled CONTROLLING A SURGICAL INSTRUMENT ACCORDING TO SENSED CLOSURE PARAMETERS;

U.S. patent application Ser. No. 16/024,067, titled SYSTEMS FOR ADJUSTING END EFFECTOR PARAMETERS BASED ON PERIOPERATIVE INFORMATION;

U.S. patent application Ser. No. 16/024,075, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING;

U.S. patent application Ser. No. 16/024,083, titled SAFETY SYSTEMS FOR SMART POWERED SURGICAL STAPLING;

U.S. patent application Ser. No. 16/024,094, titled SURGICAL SYSTEMS FOR DETECTING END EFFECTOR TISSUE DISTRIBUTION IRREGULARITIES;

U.S. patent application Ser. No. 16/024,138, titled SYSTEMS FOR DETECTING PROXIMITY OF SURGICAL END EFFECTOR TO CANCEROUS TISSUE;

U.S. patent application Ser. No. 16/024,150, titled SURGICAL INSTRUMENT CARTRIDGE SENSOR ASSEMBLIES;

U.S. patent application Ser. No. 16/024,160, titled VARIABLE OUTPUT CARTRIDGE SENSOR ASSEMBLY;

U.S. patent application Ser. No. 16/024,124, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE ELECTRODE;

U.S. patent application Ser. No. 16/024,132, titled SURGICAL INSTRUMENT HAVING A FLEXIBLE CIRCUIT;

U.S. patent application Ser. No. 16/024,141, titled SURGICAL INSTRUMENT WITH A TISSUE MARKING ASSEMBLY;

U.S. patent application Ser. No. 16/024,162, titled SURGICAL SYSTEMS WITH PRIORITIZED DATA TRANSMISSION CAPABILITIES;

U.S. patent application Ser. No. 16/024,066, titled SURGICAL EVACUATION SENSING AND MOTOR CONTROL;

U.S. patent application Ser. No. 16/024,096, titled SURGICAL EVACUATION SENSOR ARRANGEMENTS;

U.S. patent application Ser. No. 16/024,116, titled SURGICAL EVACUATION FLOW PATHS;

U.S. patent application Ser. No. 16/024,149, titled SURGICAL EVACUATION SENSING AND GENERATOR CONTROL;

U.S. patent application Ser. No. 16/024,180, titled SURGICAL EVACUATION SENSING AND DISPLAY;

U.S. patent application Ser. No. 16/024,245, titled COMMUNICATION OF SMOKE EVACUATION SYSTEM PARAMETERS TO HUB OR CLOUD IN SMOKE EVACUATION MODULE FOR INTERACTIVE SURGICAL PLATFORM;

U.S. patent application Ser. No. 16/024,258, titled SMOKE EVACUATION SYSTEM INCLUDING A SEGMENTED CONTROL CIRCUIT FOR INTERACTIVE SURGICAL PLATFORM;

U.S. patent application Ser. No. 16/024,265, titled SURGICAL EVACUATION SYSTEM WITH A COMMUNICATION CIRCUIT FOR COMMUNICATION BETWEEN A FILTER AND A SMOKE EVACUATION DEVICE; and

U.S. patent application Ser. No. 16/024,273, titled DUAL IN-SERIES LARGE AND SMALL DROPLET FILTERS.

Applicant of the present application owns the following U.S. patent applications, filed on Mar. 29, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

U.S. patent application Ser. No. 15/940,641, titled INTERACTIVE SURGICAL SYSTEMS WITH ENCRYPTED COMMUNICATION CAPABILITIES;

U.S. patent application Ser. No. 15/940,648, titled INTERACTIVE SURGICAL SYSTEMS WITH CONDITION HANDLING OF DEVICES AND DATA CAPABILITIES;

U.S. patent application Ser. No. 15/940,656, titled SURGICAL HUB COORDINATION OF CONTROL AND COMMUNICATION OF OPERATING ROOM DEVICES;

U.S. patent application Ser. No. 15/940,666, titled SPATIAL AWARENESS OF SURGICAL HUBS IN OPERATING ROOMS;

U.S. patent application Ser. No. 15/940,670, titled COOPERATIVE UTILIZATION OF DATA DERIVED FROM SECONDARY SOURCES BY INTELLIGENT SURGICAL HUBS;

U.S. patent application Ser. No. 15/940,677, titled SURGICAL HUB CONTROL ARRANGEMENTS;

U.S. patent application Ser. No. 15/940,632, titled DATA STRIPPING METHOD TO INTERROGATE PATIENT RECORDS AND CREATE ANONYMIZED RECORD;

U.S. patent application Ser. No. 15/940,640, titled COMMUNICATION HUB AND STORAGE DEVICE FOR STORING PARAMETERS AND STATUS OF A SURGICAL DEVICE TO BE SHARED WITH CLOUD BASED ANALYTICS SYSTEMS;

U.S. patent application Ser. No. 15/940,645, titled SELF DESCRIBING DATA PACKETS GENERATED AT AN ISSUING INSTRUMENT;

U.S. patent application Ser. No. 15/940,649, titled DATA PAIRING TO INTERCONNECT A DEVICE MEASURED PARAMETER WITH AN OUTCOME;

U.S. patent application Ser. No. 15/940,654, titled SURGICAL HUB SITUATIONAL AWARENESS;

U.S. patent application Ser. No. 15/940,663, titled SURGICAL SYSTEM DISTRIBUTED PROCESSING;

U.S. patent application Ser. No. 15/940,668, titled AGGREGATION AND REPORTING OF SURGICAL HUB DATA;

U.S. patent application Ser. No. 15/940,671, titled SURGICAL HUB SPATIAL AWARENESS TO DETERMINE DEVICES IN OPERATING THEATER;

U.S. patent application Ser. No. 15/940,686, titled DISPLAY OF ALIGNMENT OF STAPLE CARTRIDGE TO PRIOR LINEAR STAPLE LINE;

U.S. patent application Ser. No. 15/940,700, titled STERILE FIELD INTERACTIVE CONTROL DISPLAYS;

U.S. patent application Ser. No. 15/940,629, titled COMPUTER IMPLEMENTED INTERACTIVE SURGICAL SYSTEMS;

U.S. patent application Ser. No. 15/940,704, titled USE OF LASER LIGHT AND RED-GREEN-BLUE COLORATION TO DETERMINE PROPERTIES OF BACK SCATTERED LIGHT;

U.S. patent application Ser. No. 15/940,722, titled CHARACTERIZATION OF TISSUE IRREGULARITIES THROUGH THE USE OF MONO-CHROMATIC LIGHT REFRACTIVITY;

U.S. patent application Ser. No. 15/940,742, titled DUAL CMOS ARRAY IMAGING;

U.S. patent application Ser. No. 15/940,636, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL DEVICES;

U.S. patent application Ser. No. 15/940,653, titled ADAPTIVE CONTROL PROGRAM UPDATES FOR SURGICAL HUBS;

U.S. patent application Ser. No. 15/940,660, titled CLOUD-BASED MEDICAL ANALYTICS FOR CUSTOMIZATION AND RECOMMENDATIONS TO A USER;

U.S. patent application Ser. No. 15/940,679, titled CLOUD-BASED MEDICAL ANALYTICS FOR LINKING OF LOCAL USAGE TRENDS WITH THE RESOURCE ACQUISITION BEHAVIORS OF LARGER DATA SET;

U.S. patent application Ser. No. 15/940,694, titled CLOUD-BASED MEDICAL ANALYTICS FOR MEDICAL FACILITY SEGMENTED INDIVIDUALIZATION OF INSTRUMENT FUNCTION;

U.S. patent application Ser. No. 15/940,634, titled CLOUD-BASED MEDICAL ANALYTICS FOR SECURITY AND AUTHENTICATION TRENDS AND REACTIVE MEASURES;

U.S. patent application Ser. No. 15/940,706, titled DATA HANDLING AND PRIORITIZATION IN A CLOUD ANALYTICS NETWORK;

U.S. patent application Ser. No. 15/940,675, titled CLOUD INTERFACE FOR COUPLED SURGICAL DEVICES;

U.S. patent application Ser. No. 15/940,627, titled DRIVE ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;

U.S. patent application Ser. No. 15/940,637, titled COMMUNICATION ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;

- U.S. patent application Ser. No. 15/940,642, titled CONTROLS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. patent application Ser. No. 15/940,676, titled AUTOMATIC TOOL ADJUSTMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. patent application Ser. No. 15/940,680, titled CONTROLLERS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. patent application Ser. No. 15/940,683, titled COOPERATIVE SURGICAL ACTIONS FOR ROBOT-ASSISTED SURGICAL PLATFORMS;
- U.S. patent application Ser. No. 15/940,690, titled DISPLAY ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS; and
- U.S. patent application Ser. No. 15/940,711, titled SENSING ARRANGEMENTS FOR ROBOT-ASSISTED SURGICAL PLATFORMS.

Applicant of the present application owns the following U.S. Provisional patent applications, filed on Mar. 8, 2018, the disclosure of each of which is herein incorporated by reference in its entirety:

- U.S. Provisional Patent Application No. 62/640,417, titled TEMPERATURE CONTROL IN ULTRASONIC DEVICE AND CONTROL SYSTEM THEREFOR; and
- U.S. Provisional Patent Application No. 62/640,415, titled ESTIMATING STATE OF ULTRASONIC END EFFECTOR AND CONTROL SYSTEM THEREFOR.

It is to be understood that at least some of the figures and descriptions of the invention have been simplified to illustrate elements that are relevant for a clear understanding of the invention, while eliminating, for purposes of clarity, other elements that those of ordinary skill in the art will appreciate may also comprise a portion of the invention. However, because such elements are well known in the art, and because they do not facilitate a better understanding of the invention, a description of such elements is not provided herein.

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof In the drawings, similar symbols and reference characters typically identify similar components throughout several views, unless context dictates otherwise. The illustrative aspects described in the detailed description, drawings and claims are not meant to be limiting. Other aspects may be utilized, and other changes may be made, without departing from the scope of the technology described herein.

The following description of certain examples of the technology should not be used to limit its scope. Other examples, features, aspects, embodiments, and advantages of the technology will become apparent to those skilled in the art from the following description, which is by way of illustration, one of the best modes contemplated for carrying out the technology. As will be realized, the technology described herein is capable of other different and obvious aspects, all without departing from the technology. Accordingly, the drawings and descriptions should be regarded as illustrative in nature and not restrictive.

It is further understood that any one or more of the teachings, expressions, aspects, embodiments, examples, etc., described herein may be combined with any one or more of the other teachings, expressions, aspects, embodiments, examples, etc., that are described herein. The following described teachings, expressions, aspects, embodiments, examples, etc., should therefore not be viewed in isolation relative to each other. Various suitable ways in which the teachings herein may be combined will be readily apparent to those of ordinary skill in the art in view of the teachings herein. Such modifications and variations are intended to be included within the scope of the claims.

Before explaining the various aspects of the surgical system, the surgical instrument, the flexible circuit and the flexible electrode assembly in detail, it should be noted that the various aspects disclosed herein are not limited in their application or use to the details of construction and arrangement of parts illustrated in the accompanying drawings and description. Rather, the disclosed aspects may be positioned or incorporated in other aspects, embodiments, variations, and modifications thereof and may be practiced or carried out in various ways. Accordingly, aspects of the surgical system, the surgical instrument, the flexible circuit, and the flexible electrode assembly disclosed herein are illustrative in nature and are not meant to limit the scope or application thereof. Furthermore, unless otherwise indicated, the terms and expressions employed herein have been chosen for the purpose of describing the aspects for the convenience of the reader and are not meant to limit the scope thereof. In addition, it should be understood that any one or more of the disclosed aspects, expressions of aspects, and/or examples thereof, can be combined with any one or more of the other disclosed aspects, expressions of aspects, and/or examples thereof, without limitation.

Also, in the following description, it is to be understood that terms such as inward, outward, upward, downward, above, below, left, right, interior, exterior, and the like are words of convenience and are not to be construed as limiting terms. Terminology used herein is not meant to be limiting insofar as devices described herein, or portions thereof, may be attached or utilized in other orientations. The various aspects will be described in more detail with reference to the drawings.

As described in more detail hereinbelow, aspects of the invention may be implemented by a computing device and/or a computer program stored on a computer-readable medium. The computer-readable medium may comprise a disk, a device, and/or a propagated signal.

Referring to FIG. **1**, a computer-implemented interactive surgical system **100** includes one or more surgical systems **102** and a cloud-based system (e.g., the cloud **104** that may include a remote server **113** coupled to a storage device **105**). Each surgical system **102** includes at least one surgical hub **106** in communication with the cloud **104** that may include a remote server **113**. In one example, as illustrated in FIG. **1**, the surgical system **102** includes a visualization system **108**, a robotic system **110**, and a handheld intelligent surgical instrument **112**, which are configured to communicate with one another and/or surgical hub **106**. In some aspects, a surgical system **102** may include an M number of hubs **106**, an N number of visualization systems **108**, an O number of robotic systems **110**, and a P number of handheld intelligent surgical instruments **112**, where M, N, O, and P are integers greater than or equal to one.

FIG. **3** depicts an example of a surgical system **102** being used to perform a surgical procedure on a patient who is lying down on an operating table **114** in a surgical operating room **116**. A robotic system **110** is used in the surgical procedure as a part of the surgical system **102**. The robotic system **110** includes a surgeon's console **118**, a patient side cart **120** (surgical robot), and a surgical robotic hub **122**. The patient side cart **120** can manipulate at least one removably coupled surgical tool **117** through a minimally invasive incision in the body of the patient while the surgeon views the surgical site through the surgeon's console **118**. An

image of the surgical site can be obtained by a medical imaging device **124**, which can be manipulated by the patient side cart **120** to orient the imaging device **124**. The robotic hub **122** can be used to process the images of the surgical site for subsequent display to the surgeon through the surgeon's console **118**.

Other types of robotic systems can be readily adapted for use with the surgical system **102**. Various examples of robotic systems and surgical tools that are suitable for use with the present disclosure are described in U.S. Provisional Patent Application Ser. No. 62/611,339, titled ROBOT ASSISTED SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

Various examples of cloud-based analytics that are performed by the cloud **104**, and are suitable for use with the present disclosure, are described in U.S. Provisional Patent Application Ser. No. 62/611,340, titled CLOUD-BASED MEDICAL ANALYTICS, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

In various aspects, the imaging device **124** includes at least one image sensor and one or more optical components. Suitable image sensors include, but are not limited to, Charge-Coupled Device (CCD) sensors and Complementary Metal-Oxide Semiconductor (CMOS) sensors.

The optical components of the imaging device **124** may include one or more illumination sources and/or one or more lenses. The one or more illumination sources may be directed to illuminate portions of the surgical field. The one or more image sensors may receive light reflected or refracted from the surgical field, including light reflected or refracted from tissue and/or surgical instruments.

The one or more illumination sources may be configured to radiate electromagnetic energy in the visible spectrum as well as the invisible spectrum. The visible spectrum, sometimes referred to as the optical spectrum or luminous spectrum, is that portion of the electromagnetic spectrum that is visible to (i.e., can be detected by) the human eye and may be referred to as visible light or simply light. A typical human eye will respond to wavelengths in air that are from about 380 nm to about 750 nm.

The invisible spectrum (i.e., the non-luminous spectrum) is that portion of the electromagnetic spectrum that lies below and above the visible spectrum (i.e., wavelengths below about 380 nm and above about 750 nm). The invisible spectrum is not detectable by the human eye. Wavelengths greater than about 750 nm are longer than the red visible spectrum, and they become invisible infrared (IR), microwave, and radio electromagnetic radiation. Wavelengths less than about 380 nm are shorter than the violet spectrum, and they become invisible ultraviolet, x-ray, and gamma ray electromagnetic radiation.

In various aspects, the imaging device **124** is configured for use in a minimally invasive procedure. Examples of imaging devices suitable for use with the present disclosure include, but not limited to, an arthroscope, angioscope, bronchoscope, choledochoscope, colonoscope, cytoscope, duodenoscope, enteroscope, esophagogastro-duodenoscope (gastroscope), endoscope, laryngoscope, nasopharyngo-neproscope, sigmoidoscope, thoracoscope, and ureteroscope.

In one aspect, the imaging device employs multi-spectrum monitoring to discriminate topography and underlying structures. A multi-spectral image is one that captures image data within specific wavelength ranges across the electromagnetic spectrum. The wavelengths may be separated by filters or by the use of instruments that are sensitive to particular wavelengths, including light from frequencies beyond the visible light range, e.g., IR and ultraviolet. Spectral imaging can allow extraction of additional information the human eye fails to capture with its receptors for red, green, and blue. The use of multi-spectral imaging is described in greater detail under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. Multi-spectrum monitoring can be a useful tool in relocating a surgical field after a surgical task is completed to perform one or more of the previously described tests on the treated tissue.

It is axiomatic that strict sterilization of the operating room and surgical equipment is required during any surgery. The strict hygiene and sterilization conditions required in a "surgical theater," i.e., an operating or treatment room, necessitate the highest possible sterility of all medical devices and equipment. Part of that sterilization process is the need to sterilize anything that comes in contact with the patient or penetrates the sterile field, including the imaging device **124** and its attachments and components. It will be appreciated that the sterile field may be considered a specified area, such as within a tray or on a sterile towel, that is considered free of microorganisms, or the sterile field may be considered an area, immediately around a patient, who has been prepared for a surgical procedure. The sterile field may include the scrubbed team members, who are properly attired, and all furniture and fixtures in the area.

In various aspects, the visualization system **108** includes one or more imaging sensors, one or more image processing units, one or more storage arrays, and one or more displays that are strategically arranged with respect to the sterile field, as illustrated in FIG. **2**. In one aspect, the visualization system **108** includes an interface for HL7, PACS, and EMR. Various components of the visualization system **108** are described under the heading "Advanced Imaging Acquisition Module" in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety.

As illustrated in FIG. **2**, a primary display **119** is positioned in the sterile field to be visible to an operator at the operating table **114**. In addition, a visualization tower **111** is positioned outside the sterile field. The visualization tower **111** includes a first non-sterile display **107** and a second non-sterile display **109**, which face away from each other. The visualization system **108**, guided by surgical hub **106**, is configured to utilize the displays **107**, **109**, and **119** to coordinate information flow to operators inside and outside the sterile field. For example, surgical hub **106** may cause the visualization system **108** to display a snapshot of a surgical site, as recorded by an imaging device **124**, on a non-sterile display **107** or **109**, while maintaining a live feed of the surgical site on the primary display **119**. The snap-shot on the non-sterile display **107** or **109** can permit a non-sterile operator to perform a diagnostic step relevant to the surgical procedure, for example.

In one aspect, surgical hub **106** is also configured to route a diagnostic input or feedback entered by a nonsterile operator at the visualization tower **111** to the primary display **119** within the sterile field, where it can be viewed by a sterile operator at the operating table. In one example, the input can be in the form of a modification to the snapshot

displayed on the non-sterile display **107** or **109**, which can be routed to the primary display **119** by surgical hub **106**.

Referring to FIG. **2**, a surgical instrument **112** is being used in the surgical procedure as part of the surgical system **102**. Surgical hub **106** is also configured to coordinate information flow to a display of the surgical instrument **112**. For example, see U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety. A diagnostic input or feedback entered by a non-sterile operator at the visualization tower **111** can be routed by surgical hub **106** to the surgical instrument display **115** within the sterile field, where it can be viewed by the operator of the surgical instrument **112**. Example surgical instruments that are suitable for use with the surgical system **102** are described under the heading "Surgical Instrument Hardware" and in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, the disclosure of which is herein incorporated by reference in its entirety, for example.

Referring now to FIG. **3**, a surgical hub **106** is depicted in communication with a visualization system **108**, a robotic system **110**, and a handheld intelligent surgical instrument **112**. Surgical hub **106** includes a surgical hub display **135**, an imaging module **138**, a generator module **140**, a communication module **130**, a processor module **132**, and a storage array **134**. In certain aspects, as illustrated in FIG. **3**, surgical hub **106** further includes a smoke evacuation module **126** and/or a suction/irrigation module **128**.

During a surgical procedure, energy application to tissue, for sealing and/or cutting, is generally associated with smoke evacuation, suction of excess fluid, and/or irrigation of the tissue. Fluid, power, and/or data lines from different sources are often entangled during the surgical procedure. Valuable time can be lost addressing this issue during a surgical procedure. Detangling the lines may necessitate disconnecting the lines from their respective modules, which may require resetting the modules. Surgical hub modular enclosure **136** offers a unified environment for managing the power, data, and fluid lines, which reduces the frequency of entanglement between such lines.

Aspects of the present disclosure present a surgical hub for use in a surgical procedure that involves energy application to tissue at a surgical site. The surgical hub includes a surgical hub enclosure and a combo generator module slidably receivable in a docking station of surgical hub enclosure. The docking station includes data and power contacts. The combo generator module includes two or more of an ultrasonic energy generator component, a bipolar RF energy generator component, and a monopolar RF energy generator component that are housed in a single unit. In one aspect, the combo generator module also includes a smoke evacuation component, at least one energy delivery cable for connecting the combo generator module to a surgical instrument; at least one smoke evacuation component configured to evacuate smoke, fluid, and/or particulates generated by the application of therapeutic energy to the tissue; and a fluid line extending from the remote surgical site to the smoke evacuation component.

In one aspect, the fluid line is a first fluid line and a second fluid line extends from the remote surgical site to a suction and irrigation module slidably received in surgical hub enclosure. In one aspect, surgical hub enclosure comprises a fluid interface.

Certain surgical procedures may require the application of more than one energy type to the tissue. One energy type may be more beneficial for cutting the tissue, while another different energy type may be more beneficial for sealing the tissue. For example, a bipolar generator can be used to seal the tissue while an ultrasonic generator can be used to cut the sealed tissue. Aspects of the present disclosure present a solution where a surgical hub modular enclosure **136** is configured to accommodate different generators, and facilitate an interactive communication therebetween. One of the advantages of surgical hub modular enclosure **136** is enabling the quick removal and/or replacement of various modules.

Aspects of the present disclosure present a modular surgical enclosure for use in a surgical procedure that involves energy application to tissue. The modular surgical enclosure includes a first energy-generator module, configured to generate a first energy for application to the tissue, and a first docking station comprising a first docking port that includes first data and power contacts, wherein the first energy-generator module is slidably movable into an electrical engagement with the power and data contacts and wherein the first energy-generator module is slidably movable out of the electrical engagement with the first power and data contacts.

Further to the above, the modular surgical enclosure also includes a second energy-generator module configured to generate a second energy, different than the first energy, for application to the tissue, and a second docking station comprising a second docking port that includes second data and power contacts, wherein the second energy-generator module is slidably movable into an electrical engagement with the power and data contacts, and wherein the second energy-generator module is slidably movable out of the electrical engagement with the second power and data contacts.

In addition, the modular surgical enclosure also includes a communication bus between the first docking port and the second docking port, configured to facilitate communication between the first energy-generator module and the second energy-generator module.

Referring to FIGS. **3-7**, aspects of the present disclosure are presented for a surgical hub modular enclosure **136** that allows the modular integration of a generator module **140**, a smoke evacuation module **126**, and a suction/irrigation module **128**. Surgical hub modular enclosure **136** further facilitates interactive communication between the modules **140**, **126**, **128**. As illustrated in FIG. **5**, the generator module **140** can be a generator module with integrated monopolar, bipolar, and ultrasonic components supported in a single housing unit **139** slidably insertable into surgical hub modular enclosure **136**. As illustrated in FIG. **5**, the generator module **140** can be configured to connect to a monopolar device **146**, a bipolar device **147**, and an ultrasonic device **148**. Alternatively, the generator module **140** may comprise a series of monopolar, bipolar, and/or ultrasonic generator modules that interact through surgical hub modular enclosure **136**. Surgical hub modular enclosure **136** can be configured to facilitate the insertion of multiple generators and interactive communication between the generators docked into surgical hub modular enclosure **136** so that the generators would act as a single generator.

In one aspect, surgical hub modular enclosure **136** comprises a modular power and communication backplane **149** with external and wireless communication headers to enable the removable attachment of the modules **140**, **126**, **128** and interactive communication therebetween.

In one aspect, surgical hub modular enclosure **136** includes docking stations, or drawers, **151**, herein also

referred to as drawers, which are configured to slidably receive the modules **140**, **126**, **128**. FIG. **4** illustrates a partial perspective view of a surgical hub enclosure **136** and a combo generator module **145** slidably receivable in a docking station **151** of the surgical hub enclosure **136**. A docking port **152** with power and data contacts on a rear side of the combo generator module **145** is configured to engage a corresponding docking port **150** with power and data contacts of a corresponding docking station **151** of surgical hub modular enclosure **136** as the combo generator module **145** is slid into position within the corresponding docking station **151** of surgical hub module enclosure **136**. In one aspect, the combo generator module **145** includes a bipolar, ultrasonic, and monopolar module and a smoke evacuation module integrated together into a single housing unit **139**, as illustrated in FIG. **5**.

In various aspects, the smoke evacuation module **126** includes a fluid line **154** that conveys captured/collected smoke and/or fluid away from a surgical site and to, for example, the smoke evacuation module **126**. Vacuum suction originating from the smoke evacuation module **126** can draw the smoke into an opening of a utility conduit at the surgical site. The utility conduit, coupled to the fluid line, can be in the form of a flexible tube terminating at the smoke evacuation module **126**. The utility conduit and the fluid line define a fluid path extending toward the smoke evacuation module **126** that is received in surgical hub enclosure **136**.

In various aspects, the suction/irrigation module **128** is coupled to a surgical tool comprising an aspiration fluid line and a suction fluid line. In one example, the aspiration and suction fluid lines are in the form of flexible tubes extending from the surgical site toward the suction/irrigation module **128**. One or more drive systems can be configured to cause irrigation and aspiration of fluids to and from the surgical site.

In one aspect, the surgical tool includes a shaft having an end effector at a distal end thereof and at least one energy treatment associated with the end effector, an aspiration tube, and an irrigation tube. The aspiration tube can have an inlet port at a distal end thereof and the aspiration tube extends through the shaft. Similarly, an irrigation tube can extend through the shaft and can have an inlet port in proximity to the energy deliver implement. The energy deliver implement is configured to deliver ultrasonic and/or RF energy to the surgical site and is coupled to the generator module **140** by a cable extending initially through the shaft.

The irrigation tube can be in fluid communication with a fluid source, and the aspiration tube can be in fluid communication with a vacuum source. The fluid source and/or the vacuum source can be housed in the suction/irrigation module **128**. In one example, the fluid source and/or the vacuum source can be housed in surgical hub enclosure **136** separately from the suction/irrigation module **128**. In such example, a fluid interface can be configured to connect the suction/irrigation module **128** to the fluid source and/or the vacuum source.

In one aspect, the modules **140**, **126**, **128** and/or their corresponding docking stations on surgical hub modular enclosure **136** may include alignment features that are configured to align the docking ports of the modules into engagement with their counterparts in the docking stations of surgical hub modular enclosure **136**. For example, as illustrated in FIG. **4**, the combo generator module **145** includes side brackets **155** that are configured to slidably engage with corresponding brackets **156** of the corresponding docking station **151** of surgical hub modular enclosure **136**. The brackets cooperate to guide the docking port contacts of the combo generator module **145** into an electrical engagement with the docking port contacts of surgical hub modular enclosure **136**.

In some aspects, the drawers **151** of surgical hub modular enclosure **136** are the same, or substantially the same size, and the modules are adjusted in size to be received in the drawers **151**. For example, the side brackets **155** and/or **156** can be larger or smaller depending on the size of the module. In other aspects, the drawers **151** are different in size and are each designed to accommodate a particular module.

Furthermore, the contacts of a particular module can be keyed for engagement with the contacts of a particular drawer to avoid inserting a module into a drawer with mismatching contacts.

As illustrated in FIG. **4**, the docking port **150** of one drawer **151** can be coupled to the docking port **150** of another drawer **151** through a communications link **157** to facilitate an interactive communication between the modules housed in surgical hub modular enclosure **136**. The docking ports **150** of surgical hub modular enclosure **136** may alternatively, or additionally, facilitate a wireless interactive communication between the modules housed in surgical hub modular enclosure **136**. Any suitable wireless communication can be employed, such as, for example, Air Titan-Bluetooth.

FIG. **6** illustrates individual power bus attachments for a plurality of lateral docking ports of a lateral modular housing **160** configured to receive a plurality of modules of a surgical hub **206**. The lateral modular housing **160** is configured to laterally receive and interconnect the modules **161**. The modules **161** are slidably inserted into docking stations **162** of lateral modular housing **160**, which includes a backplane for interconnecting the modules **161**. As illustrated in FIG. **6**, the modules **161** are arranged laterally in the lateral modular housing **160**. Alternatively, the modules **161** may be arranged vertically in a vertical modular housing.

FIG. **7** illustrates a vertical modular housing **164** configured to receive a plurality of modules **165** of the surgical hub **106**. The modules **165** are slidably inserted into docking stations, or drawers, **167** of vertical modular housing **164**, which includes a backplane for interconnecting the modules **165**. Although the drawers **167** of the vertical modular housing **164** are arranged vertically, in certain instances, a vertical modular housing **164** may include drawers that are arranged laterally. Furthermore, the modules **165** may interact with one another through the docking ports of the vertical modular housing **164**. In the example of FIG. **7**, a display **177** is provided for displaying data relevant to the operation of the modules **165**. In addition, the vertical modular housing **164** includes a master module **178** housing a plurality of sub-modules that are slidably received in the master module **178**.

In various aspects, the imaging module **138** comprises an integrated video processor and a modular light source and is adapted for use with various imaging devices. In one aspect, the imaging device is comprised of a modular housing that can be assembled with a light source module and a camera module. The housing can be a disposable housing. In at least one example, the disposable housing is removably coupled to a reusable controller, a light source module, and a camera module. The light source module and/or the camera module can be selectively chosen depending on the type of surgical procedure. In one aspect, the camera module comprises a CCD sensor. In another aspect, the camera module comprises a CMOS sensor. In another aspect, the camera module is configured for scanned beam imaging. Likewise, the light

source module can be configured to deliver a white light or a different light, depending on the surgical procedure.

During a surgical procedure, removing a surgical device from the surgical field and replacing it with another surgical device that includes a different camera or a different light source can be inefficient. Temporarily losing sight of the surgical field may lead to undesirable consequences. The module imaging device of the present disclosure is configured to permit the replacement of a light source module or a camera module midstream during a surgical procedure, without having to remove the imaging device from the surgical field.

In one aspect, the imaging device comprises a tubular housing that includes a plurality of channels. A first channel is configured to slidably receive the camera module, which can be configured for a snap-fit engagement with the first channel. A second channel is configured to slidably receive the light source module, which can be configured for a snap-fit engagement with the second channel. In another example, the camera module and/or the light source module can be rotated into a final position within their respective channels. A threaded engagement can be employed in lieu of the snap-fit engagement.

In various examples, multiple imaging devices are placed at different positions in the surgical field to provide multiple views. The imaging module **138** can be configured to switch between the imaging devices to provide an optimal view. In various aspects, the imaging module **138** can be configured to integrate the images from the different imaging device.

Various image processors and imaging devices suitable for use with the present disclosure are described in U.S. Pat. No. 7,995,045, titled COMBINED SBI AND CONVENTIONAL IMAGE PROCESSOR, which issued on Aug. 9, 2011, which is herein incorporated by reference in its entirety. In addition, U.S. Pat. No. 7,982,776, titled SBI MOTION ARTIFACT REMOVAL APPARATUS AND METHOD, which issued on Jul. 19, 2011, which is herein incorporated by reference in its entirety, describes various systems for removing motion artifacts from image data. Such systems can be integrated with the imaging module **138**. Furthermore, U.S. Patent Application Publication No. 2011/0306840, titled CONTROLLABLE MAGNETIC SOURCE TO FIXTURE INTRACORPOREAL APPARATUS, published on Dec. 15, 2011, and U.S. Patent Application Publication No. 2014/0243597, titled SYSTEM FOR PERFORMING A MINIMALLY INVASIVE SURGICAL PROCEDURE, published on Aug. 28, 2014, the disclosure of each of which is herein incorporated by reference in its entirety.

FIG. **8** illustrates a surgical data network **201** comprising a modular communication hub **203** configured to connect modular devices located in one or more operating theaters of a healthcare facility, or any room in a healthcare facility specially equipped for surgical operations, to a cloud-based system (e.g., the cloud **204** that may include a remote server **213** coupled to a storage device **205** (FIG. **9**)). In one aspect, the modular communication hub **203** comprises a network hub **207** and/or a network switch **209** in communication with a network router. The modular communication hub **203** also can be coupled to a local computer system **210** to provide local computer processing and data manipulation. The surgical data network **201** may be configured as passive, intelligent, or switching. A passive surgical data network serves as a conduit for the data, enabling it to go from one device (or segment) to another and to the cloud computing resources. An intelligent surgical data network includes additional features to enable the traffic passing through the surgical data network to be monitored and to configure each port in the network hub **207** or network switch **209**. An intelligent surgical data network may be referred to as a manageable hub or switch. A switching hub reads the destination address of each packet and then forwards the packet to the correct port.

Modular devices **1***a*-**1***n* located in the operating theater may be coupled to the modular communication hub **203**. The network hub **207** and/or the network switch **209** may be coupled to a network router **211** to connect the devices **1***a*-**1***n* to the cloud **204** or the local computer system **210**. Data associated with the devices **1***a*-**1***n* may be transferred to cloud-based computers via the router for remote data processing and manipulation. Data associated with the devices **1***a*-**1***n* may also be transferred to the local computer system **210** for local data processing and manipulation. Modular devices **2***a*-**2***m* located in the same operating theater also may be coupled to a network switch **209**. The network switch **209** may be coupled to the network hub **207** and/or the network router **211** to connect to the devices **2***a*-**2***m* to the cloud **204**. Data associated with the devices **2***a*-**2***m* may be transferred to the cloud **204** via the network router **211** for data processing and manipulation. Data associated with the devices **2***a*-**2***m* may also be transferred to the local computer system **210** for local data processing and manipulation.

It will be appreciated that the surgical data network **201** may be expanded by interconnecting multiple network hubs **207** and/or multiple network switches **209** with multiple network routers **211**. The modular communication hub **203** may be contained in a modular control tower configured to receive multiple devices **1***a*-**1***n*/**2***a*-**2***m*. The local computer system **210** also may be contained in a modular control tower. The modular communication hub **203** is connected to a display **212** to display images obtained by some of the devices **1***a*-**1***n*/**2***a*-**2***m*, for example during surgical procedures. In various aspects, the devices **1***a*-**1***n*/**2***a*-**2***m* may include, for example, various modules such as an imaging module **138** coupled to an endoscope, a generator module **140** coupled to an energy-based surgical device, a smoke evacuation module **126**, a suction/irrigation module **128**, a communication module **130**, a processor module **132**, a storage array **134**, a surgical device coupled to a display, and/or a non-contact sensor module, among other modular devices that may be connected to the modular communication hub **203** of the surgical data network **201**.

In one aspect, the surgical data network **201** may comprise a combination of network hub(s), network switch(es), and network router(s) connecting the devices **1***a*-**1***n*/**2***a*-**2***m* to the cloud. Any one of or all of the devices **1***a*-**1***n*/**2***a*-**2***m* coupled to the network hub or network switch may collect data in real time and transfer the data to cloud computers for data processing and manipulation. It will be appreciated that cloud computing relies on sharing computing resources rather than having local servers or personal devices to handle software applications. The word "cloud" may be used as a metaphor for "the Internet," although the term is not limited as such. Accordingly, the term "cloud computing" may be used herein to refer to "a type of Internet-based computing," where different services—such as servers, storage, and applications—are delivered to the modular communication hub **203** and/or computer system **210** located in the surgical theater (e.g., a fixed, mobile, temporary, or field operating room or space) and to devices connected to the modular communication hub **203** and/or computer system **210** through the Internet. The cloud infrastructure may be maintained by a cloud service provider. In this context, the cloud service provider may be the entity that coordinates the

usage and control of the devices **1***a*-**1***n*/**2***a*-**2***m* located in one or more operating theaters. The cloud computing services can perform a large number of calculations based on the data gathered by smart surgical instruments, robots, and other computerized devices located in the operating theater. Surgical hub hardware enables multiple devices or connections to be connected to a computer that communicates with the cloud computing resources and storage.

Applying cloud computer data processing techniques on the data collected by the devices **1***a*-**1***n*/**2***a*-**2***m*, the surgical data network provides improved surgical outcomes, reduced costs, and improved patient satisfaction. At least some of the devices **1***a*-**1***n*/**2***a*-**2***m* may be employed to view tissue states to assess leaks or perfusion of sealed tissue after a tissue sealing and cutting procedure. At least some of the devices **1***a*-**1***n*/**2***a*-**2***m* may be employed to identify pathology, such as the effects of diseases, using the cloud-based computing to examine data including images of samples of body tissue for diagnostic purposes. This includes localization and margin confirmation of tissue and phenotypes. At least some of the devices **1***a*-**1***n*/**2***a*-**2***m* may be employed to identify anatomical structures of the body using a variety of sensors integrated with imaging devices and techniques such as overlaying images captured by multiple imaging devices. The data gathered by the devices **1***a*-**1***n*/**2***a*-**2***m*, including image data, may be transferred to the cloud **204** or the local computer system **210** or both for data processing and manipulation including image processing and manipulation. The data may be analyzed to improve surgical procedure outcomes by determining if further treatment, such as the application of endoscopic intervention, emerging technologies, a targeted radiation, targeted intervention, and precise robotics to tissue-specific sites and conditions, may be pursued. Such data analysis may further employ outcome analytics processing, and using standardized approaches may provide beneficial feedback to either confirm surgical treatments and the behavior of the surgeon or suggest modifications to surgical treatments and the behavior of the surgeon.

In one implementation, the operating theater devices **1***a*-**1***n* may be connected to the modular communication hub **203** over a wired channel or a wireless channel depending on the configuration of the devices **1***a*-**1***n* to a network hub. The network hub **207** may be implemented, in one aspect, as a local network broadcast device that works on the physical layer of the Open System Interconnection (OSI) model. The network hub provides connectivity to the devices **1***a*-**1***n* located in the same operating theater network. The network hub **207** collects data in the form of packets and sends them to the router in half duplex mode. The network hub **207** does not store any media access control/Internet protocol (MAC/TP) to transfer the device data. Only one of the devices **1***a*-**1***n* can send data at a time through the network hub **207**. The network hub **207** has no routing tables or intelligence regarding where to send information and broadcasts all network data across each connection and to a remote server **213** (FIG. **9**) over the cloud **204**. The network hub **207** can detect basic network errors such as collisions, but having all information broadcast to multiple ports can be a security risk and cause bottlenecks.

In another implementation, the operating theater devices **2***a*-**2***m* may be connected to a network switch **209** over a wired channel or a wireless channel. The network switch **209** works in the data link layer of the OSI model. The network switch **209** is a multicast device for connecting the devices **2***a*-**2***m* located in the same operating theater to the network. The network switch **209** sends data in the form of frames to the network router **211** and works in full duplex mode. Multiple devices **2***a*-**2***m* can send data at the same time through the network switch **209**. The network switch **209** stores and uses MAC addresses of the devices **2***a*-**2***m* to transfer data.

The network hub **207** and/or the network switch **209** are coupled to the network router **211** for connection to the cloud **204**. The network router **211** works in the network layer of the OSI model. The network router **211** creates a route for transmitting data packets received from the network hub **207** and/or network switch **211** to cloud-based computer resources for further processing and manipulation of the data collected by any one of or all the devices **1***a*-**1***n*/**2***a*-**2***m*. The network router **211** may be employed to connect two or more different networks located in different locations, such as, for example, different operating theaters of the same healthcare facility or different networks located in different operating theaters of different healthcare facilities. The network router **211** sends data in the form of packets to the cloud **204** and works in full duplex mode. Multiple devices can send data at the same time. The network router **211** uses IP addresses to transfer data.

In one example, the network hub **207** may be implemented as a USB hub, which allows multiple USB devices to be connected to a host computer. The USB hub may expand a single USB port into several tiers so that there are more ports available to connect devices to the host system computer. The network hub **207** may include wired or wireless capabilities to receive information over a wired channel or a wireless channel. In one aspect, a wireless USB short-range, high-bandwidth wireless radio communication protocol may be employed for communication between the devices **1***a*-**1***n* and devices **2***a*-**2***m* located in the operating theater.

In other examples, the operating theater devices **1***a*-**1***n*/**2***a*-**2***m* may communicate to the modular communication hub **203** via Bluetooth wireless technology standard for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485 GHz) from fixed and mobile devices and building personal area networks (PANs). In other aspects, the operating theater devices **1***a*-**1***n*/**2***a*-**2***m* may communicate to the modular communication hub **203** via a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, long-term evolution (LTE), and Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, and Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter-range wireless communications such as Wi-Fi and Bluetooth, and a second communication module may be dedicated to longer-range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

The modular communication hub **203** may serve as a central connection for one or all of the operating theater devices **1***a*-**1***n*/**2***a*-**2***m* and handles a data type known as frames. Frames carry the data generated by the devices **1***a*-**1***n*/**2***a*-**2***m*. When a frame is received by the modular communication hub **203**, it is amplified and transmitted to the network router **211**, which transfers the data to the cloud computing resources by using a number of wireless or wired communication standards or protocols, as described herein.

The modular communication hub **203** can be used as a standalone device or be connected to compatible network hubs and network switches to form a larger network. The modular communication hub **203** is generally easy to install, configure, and maintain, making it a good option for networking the operating theater devices **1***a*-**1***n*/**2***a*-**2***m*.

FIG. **9** illustrates a computer-implemented interactive surgical system **200**. The computer-implemented interactive surgical system **200** is similar in many respects to the computer-implemented interactive surgical system **100**. For example, the computer-implemented interactive surgical system **200** includes one or more surgical systems **202**, which are similar in many respects to the surgical systems **102**. Each surgical system **202** includes at least one surgical hub **206** in communication with a cloud **204** that may include a remote server **213**. In one aspect, the computer-implemented interactive surgical system **200** comprises a modular control tower **236** connected to multiple operating theater devices such as, for example, intelligent surgical instruments, robots, and other computerized devices located in the operating theater. As shown in FIG. **10**, the modular control tower **236** comprises a modular communication hub **203** coupled to a computer system **210**. As illustrated in the example of FIG. **9**, the modular control tower **236** is coupled to an imaging module **238** that is coupled to an endoscope **239**, a generator module **240** that is coupled to an energy device **241**, a smoke evacuation module **226**, a suction/irrigation module **228**, a communication module **230**, a processor module **232**, a storage array **234**, a smart device/instrument **235** optionally coupled to a display **237**, and a non-contact sensor module **242**. The operating theater devices are coupled to cloud computing resources and data storage via the modular control tower **236**. A robot hub **222** also may be connected to the modular control tower **236** and to the cloud computing resources. The devices/instruments **235**, visualization system **208**, among others, may be coupled to the modular control tower **236** via wired or wireless communication standards or protocols, as described herein. The modular control tower **236** may be coupled to a surgical hub display **215** (e.g., monitor, screen) to display and overlay images received from the imaging module, device/instrument display, and/or other visualization system **208**. Surgical hub display also may display data received from devices connected to the modular control tower in conjunction with images and overlaid images.

FIG. **10** illustrates a surgical hub **206** comprising a plurality of modules coupled to the modular control tower **236**. The modular control tower **236** comprises a modular communication hub **203**, e.g., a network connectivity device, and a computer system **210** to provide local processing, visualization, and imaging, for example. As shown in FIG. **10**, the modular communication hub **203** may be connected in a tiered configuration to expand the number of modules (e.g., devices) that may be connected to the modular communication hub **203** and transfer data associated with the modules to the computer system **210**, cloud computing resources, or both. As shown in FIG. **10**, each of the network hubs/switches in the modular communication hub **203** includes three downstream ports and one upstream port. The upstream network hub/switch is connected to a processor to provide a communication connection to the cloud computing resources and a local display **217**. Communication to the cloud **204** may be made either through a wired or a wireless communication channel.

The surgical hub **206** employs a non-contact sensor module **242** to measure the dimensions of the operating theater and generate a map of the surgical theater using either ultrasonic or laser-type non-contact measurement devices. An ultrasound-based non-contact sensor module scans the operating theater by transmitting a burst of ultrasound and receiving the echo when it bounces off the perimeter walls of an operating theater as described under the heading "Surgical Hub Spatial Awareness Within an Operating Room" in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, which is herein incorporated by reference in its entirety, in which the sensor module is configured to determine the size of the operating theater and to adjust Bluetooth-pairing distance limits. A laser-based non-contact sensor module scans the operating theater by transmitting laser light pulses, receiving laser light pulses that bounce off the perimeter walls of the operating theater, and comparing the phase of the transmitted pulse to the received pulse to determine the size of the operating theater and to adjust Bluetooth pairing distance limits, for example.

The computer system **210** comprises a processor **244** and a network interface **245**. The processor **244** is coupled to a communication module **247**, storage **248**, memory **249**, non-volatile memory **250**, and input/output interface **251** via a system bus. The system bus can be any of several types of bus structure(s) including the memory bus or memory controller, a peripheral bus or external bus, and/or a local bus using any variety of available bus architectures including, but not limited to, 9-bit bus, Industrial Standard Architecture (ISA), Micro-Charmel Architecture (MSA), Extended ISA (EISA), Intelligent Drive Electronics (IDE), VESA Local Bus (VLB), Peripheral Component Interconnect (PCI), USB, Advanced Graphics Port (AGP), Personal Computer Memory Card International Association bus (PCMCIA), Small Computer Systems Interface (SCSI), or any other proprietary bus.

The processor **244** may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle serial random access memory (SRAM), an internal read-only memory (ROM) loaded with StellarisWare® software, a 2 KB electrically erasable programmable read-only memory (EEPROM), and/or one or more pulse width modulation (PWM) modules, one or more quadrature encoder inputs (QEI) analogs, one or more 12-bit analog-to-digital converters (ADCs) with 12 analog input channels, details of which are available for the product datasheet.

In one aspect, the processor **244** may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

The system memory includes volatile memory and non-volatile memory. The basic input/output system (BIOS), containing the basic routines to transfer information between elements within the computer system, such as during start-up, is stored in non-volatile memory. For example, the non-volatile memory can include ROM, programmable ROM (PROM), electrically programmable ROM (EPROM), EEPROM, or flash memory. Volatile memory includes ran-

dom-access memory (RAM), which acts as external cache memory. Moreover, RAM is available in many forms such as SRAM, dynamic RAM (DRAM), synchronous DRAM (SDRAM), double data rate SDRAM (DDR SDRAM), enhanced SDRAM (ESDRAM), Synchlink DRAM (SLDRAM), and direct Rambus RAM (DRRAM).

The computer system **210** also includes removable/non-removable, volatile/non-volatile computer storage media, such as for example disk storage. The disk storage includes, but is not limited to, devices like a magnetic disk drive, floppy disk drive, tape drive, Jaz drive, Zip drive, LS-60 drive, flash memory card, or memory stick. In addition, the disk storage can include storage media separately or in combination with other storage media including, but not limited to, an optical disc drive such as a compact disc ROM device (CD-ROM), compact disc recordable drive (CD-R Drive), compact disc rewritable drive (CD-RW Drive), or a digital versatile disc ROM drive (DVD-ROM). To facilitate the connection of the disk storage devices to the system bus, a removable or non-removable interface may be employed.

It is to be appreciated that the computer system **210** includes software that acts as an intermediary between users and the basic computer resources described in a suitable operating environment. Such software includes an operating system. The operating system, which can be stored on the disk storage, acts to control and allocate resources of the computer system. System applications take advantage of the management of resources by the operating system through program modules and program data stored either in the system memory or on the disk storage. It is to be appreciated that various components described herein can be implemented with various operating systems or combinations of operating systems.

A user enters commands or information into the computer system **210** through input device(s) coupled to the I/O interface **251**. The input devices include, but are not limited to, a pointing device such as a mouse, trackball, stylus, touch pad, keyboard, microphone, joystick, game pad, satellite dish, scanner, TV tuner card, digital camera, digital video camera, web camera, and the like. These and other input devices connect to the processor through the system bus via interface port(s). The interface port(s) include, for example, a serial port, a parallel port, a game port, and a USB. The output device(s) use some of the same types of ports as input device(s). Thus, for example, a USB port may be used to provide input to the computer system and to output information from the computer system to an output device. An output adapter is provided to illustrate that there are some output devices like monitors, displays, speakers, and printers, among other output devices that require special adapters. The output adapters include, by way of illustration and not limitation, video and sound cards that provide a means of connection between the output device and the system bus. It should be noted that other devices and/or systems of devices, such as remote computer(s), provide both input and output capabilities.

The computer system **210** can operate in a networked environment using logical connections to one or more remote computers, such as cloud computer(s), or local computers. The remote cloud computer(s) can be a personal computer, server, router, network PC, workstation, microprocessor-based appliance, peer device, or other common network node, and the like, and typically includes many or all of the elements described relative to the computer system. For purposes of brevity, only a memory storage device is illustrated with the remote computer(s). The remote computer(s) is logically connected to the computer system through a network interface and then physically connected via a communication connection. The network interface encompasses communication networks such as local area networks (LANs) and wide area networks (WANs). LAN technologies include Fiber Distributed Data Interface (FDDI), Copper Distributed Data Interface (CDDI), Ethernet/IEEE 802.3, Token Ring/IEEE 802.5 and the like. WAN technologies include, but are not limited to, point-to-point links, circuit-switching networks like Integrated Services Digital Networks (ISDN) and variations thereon, packet-switching networks, and Digital Subscriber Lines (DSL).

In various aspects, the computer system **210** of FIG. **10**, the imaging module **238** and/or visualization system **208**, and/or the processor module **232** of FIGS. **9-10** may comprise an image processor, image processing engine, media processor, or any specialized digital signal processor (DSP) used for the processing of digital images. The image processor may employ parallel computing with single instruction, multiple data (SIMD) or multiple instruction, multiple data (MIMD) technologies to increase speed and efficiency. The digital image processing engine can perform a range of tasks. The image processor may be a system on a chip with multicore processor architecture.

The communication connection(s) refers to the hardware/software employed to connect the network interface to the bus. While the communication connection is shown for illustrative clarity inside the computer system, it can also be external to the computer system **210**. The hardware/software necessary for connection to the network interface includes, for illustrative purposes only, internal and external technologies such as modems, including regular telephone-grade modems, cable modems, and DSL modems, ISDN adapters, and Ethernet cards.

FIG. **11** illustrates a functional block diagram of one aspect of a USB network hub **300** device, according to one aspect of the present disclosure. In the illustrated aspect, the USB network hub device **300** employs a TUSB2036 integrated circuit hub by Texas Instruments. The USB network hub **300** is a CMOS device that provides an upstream USB transceiver port **302** and up to three downstream USB transceiver ports **304**, **306**, **308** in compliance with the USB 2.0 specification. The upstream USB transceiver port **302** is a differential root data port comprising a differential data minus (DM0) input paired with a differential data plus (DP0) input. The three downstream USB transceiver ports **304**, **306**, **308** are differential data ports where each port includes differential data plus (DP1-DP3) outputs paired with differential data minus (DM1-DM3) outputs.

The USB network hub **300** device is implemented with a digital state machine instead of a microcontroller, and no firmware programming is required. Fully compliant USB transceivers are integrated into the circuit for the upstream USB transceiver port **302** and all downstream USB transceiver ports **304**, **306**, **308**. The downstream USB transceiver ports **304**, **306**, **308** support both full-speed and low-speed devices by automatically setting the slew rate according to the speed of the device attached to the ports. The USB network hub **300** device may be configured either in bus-powered or self-powered mode and includes a surgical hub power logic **312** to manage power.

The USB network hub **300** device includes a serial interface engine **310** (SIE). The SIE **310** is the front end of the USB network hub **300** hardware and handles most of the protocol described in chapter 8 of the USB specification. The SIE **310** typically comprehends signaling up to the transaction level. The functions that it handles could include:

packet recognition, transaction sequencing, SOP, EOP, RESET, and RESUME signal detection/generation, clock/data separation, non-return-to-zero invert (NRZI) data encoding/decoding and bit-stuffing, CRC generation and checking (token and data), packet ID (PID) generation and checking/decoding, and/or serial-parallel/parallel-serial conversion. The STE **310** receives a clock input **314** and is coupled to a suspend/resume logic and frame timer **316** circuit and a surgical hub repeater circuit **318** to control communication between the upstream USB transceiver port **302** and the downstream USB transceiver ports **304**, **306**, **308** through port logic circuits **320**, **322**, **324**. The STE **310** is coupled to a command decoder **326** via interface logic to control commands from a serial EEPROM via a serial EEPROM interface **330**.

In various aspects, the USB network hub **300** can connect **127** functions configured in up to six logical layers (tiers) to a single computer. Further, the USB network hub **300** can connect to all peripherals using a standardized four-wire cable that provides both communication and power distribution. The power configurations are bus-powered and self-powered modes. The USB network hub **300** may be configured to support four modes of power management: a bus-powered hub, with either individual-port power management or ganged-port power management, and the self-powered hub, with either individual-port power management or ganged-port power management. In one aspect, using a USB cable, the USB network hub **300**, the upstream USB transceiver port **302** is plugged into a USB host controller, and the downstream USB transceiver ports **304**, **306**, **308** are exposed for connecting USB compatible devices, and so forth.

FIG. **12** illustrates a logic diagram of a control system **470** of a surgical instrument or tool in accordance with one or more aspects of the present disclosure. The system **470** comprises a control circuit. The control circuit includes a microcontroller **461** comprising a processor **462** and a memory **468**. One or more of sensors **472**, **474**, **476**, for example, provide real-time feedback to the processor **462**. A motor **482**, driven by a motor driver **492**, operably couples a longitudinally movable displacement member to drive the I-beam knife element. A tracking system **480** is configured to determine the position of the longitudinally movable displacement member. The position information is provided to the processor **462**, which can be programmed or configured to determine the position of the longitudinally movable drive member as well as the position of a firing member, firing bar, and I-beam knife element. Additional motors may be provided at the tool driver interface to control I-beam firing, closure tube travel, shaft rotation, and articulation. A display **473** displays a variety of operating conditions of the instruments and may include touch screen functionality for data input. Information displayed on the display **473** may be overlaid with images acquired via endoscopic imaging modules.

In one aspect, the microcontroller **461** may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the main microcontroller **461** may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising an on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, and internal ROM loaded with StellarisWare® software, a 2 KB EEPROM, one or more PWM modules, one or more QEI analogs, and/or one or more 12-bit ADCs with 12 analog input channels, details of which are available for the product datasheet.

In one aspect, the microcontroller **461** may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

The microcontroller **461** may be programmed to perform various functions such as precise control over the speed and position of the knife and articulation systems. In one aspect, the microcontroller **461** includes a processor **462** and a memory **468**. The electric motor **482** may be a brushed direct current (DC) motor with a gearbox and mechanical links to an articulation or knife system. In one aspect, a motor driver **492** may be an A3941 available from Allegro Microsystems, Inc. Other motor drivers may be readily substituted for use in the tracking system **480** comprising an absolute positioning system. A detailed description of an absolute positioning system is described in U.S. Patent Application Publication No. 2017/0296213, titled SYSTEMS AND METHODS FOR CONTROLLING A SURGICAL STAPLING AND CUTTING INSTRUMENT, published on Oct. 19, 2017, which is herein incorporated by reference in its entirety.

The microcontroller **461** may be programmed to provide precise control over the speed and position of displacement members and articulation systems. The microcontroller **461** may be configured to compute a response in the software of the microcontroller **461**. The computed response is compared to a measured response of the actual system to obtain an "observed" response, which is used for actual feedback decisions. The observed response is a favorable, tuned value that balances the smooth, continuous nature of the simulated response with the measured response, which can detect outside influences on the system.

In one aspect, the motor **482** may be controlled by the motor driver **492** and can be employed by the firing system of the surgical instrument or tool. In various forms, the motor **482** may be a brushed DC driving motor having a maximum rotational speed of approximately 25,000 RPM. In other arrangements, the motor **482** may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The motor driver **492** may comprise an H-bridge driver comprising field-effect transistors (FETs), for example. The motor **482** can be powered by a power assembly releasably mounted to the handle assembly or tool housing for supplying control power to the surgical instrument or tool. The power assembly may comprise a battery that may include a number of battery cells connected in series that can be used as the power source to power the surgical instrument or tool. In certain circumstances, the battery cells of the power assembly may be replaceable and/or rechargeable. In at least one example, the battery cells can be lithium-ion batteries which can be couplable to and separable from the power assembly.

The motor driver **492** may be an A3941 available from Allegro Microsystems, Inc. The A3941 motor **492** is a full-bridge controller for use with external N-channel power metal-oxide semiconductor field-effect transistors (MOSFETs) specifically designed for inductive loads, such as brush DC motors. The driver **492** comprises a unique charge pump regulator that provides full (>10 V) gate drive for battery voltages down to 7 V and allows the A3941 to

operate with a reduced gate drive, down to 5.5 V. A bootstrap capacitor may be employed to provide the above battery supply voltage required for N-channel MOSFETs. An internal charge pump for the high-side drive allows DC (100% duty cycle) operation. The full bridge can be driven in fast or slow decay modes using diode or synchronous rectification. In the slow decay mode, current recirculation can be through the high-side or the lowside FETs. The power FETs are protected from shoot-through by resistor-adjustable dead time. Integrated diagnostics provide indications of undervoltage, overtemperature, and power bridge faults and can be configured to protect the power MOSFETs undermost short circuit conditions. Other motor drivers may be readily substituted for use in the tracking system **480** comprising an absolute positioning system.

The tracking system **480** comprises a controlled motor drive circuit arrangement comprising a position sensor **472** according to one aspect of this disclosure. The position sensor **472** for an absolute positioning system provides a unique position signal corresponding to the location of a displacement member. In one aspect, the displacement member represents a longitudinally movable drive member comprising a rack of drive teeth for meshing engagement with a corresponding drive gear of a gear reducer assembly. In other aspects, the displacement member represents the firing member, which could be adapted and configured to include a rack of drive teeth. In yet another aspect, the displacement member represents a firing bar or the I-beam, each of which can be adapted and configured to include a rack of drive teeth. Accordingly, as used herein, the term displacement member is used generically to refer to any movable member of the surgical instrument or tool such as the drive member, the firing member, the firing bar, the I-beam, or any element that can be displaced. In one aspect, the longitudinally movable drive member is coupled to the firing member, the firing bar, and the I-beam. Accordingly, the absolute positioning system can, in effect, track the linear displacement of the I-beam by tracking the linear displacement of the longitudinally movable drive member. In various other aspects, the displacement member may be coupled to any position sensor **472** suitable for measuring linear displacement. Thus, the longitudinally movable drive member, the firing member, the firing bar, or the I-beam, or combinations thereof, may be coupled to any suitable linear displacement sensor. Linear displacement sensors may include contact or non-contact displacement sensors. Linear displacement sensors may comprise linear variable differential transformers (LVDT), differential variable reluctance transducers (DVRT), a slide potentiometer, a magnetic sensing system comprising a movable magnet and a series of linearly arranged Hall-effect sensors, a magnetic sensing system comprising a fixed magnet and a series of movable, linearly arranged Hall-effect sensors, an optical sensing system comprising a movable light source and a series of linearly arranged photo diodes or photo detectors, an optical sensing system comprising a fixed light source and a series of movable linearly, arranged photo diodes or photo detectors, or any combination thereof.

The electric motor **482** can include a rotatable shaft that operably interfaces with a gear assembly that is mounted in meshing engagement with a set, or rack of drive teeth on the displacement member. A sensor element may be operably coupled to a gear assembly such that a single revolution of the position sensor **472** element corresponds to some linear longitudinal translation of the displacement member. An arrangement of gearing and sensors can be connected to the linear actuator, via a rack and pinion arrangement, or a rotary actuator, via a spur gear or other connection. A power source supplies power to the absolute positioning system and an output indicator may display the output of the absolute positioning system. The displacement member represents the longitudinally movable drive member comprising a rack of drive teeth formed thereon for meshing engagement with a corresponding drive gear of the gear reducer assembly. The displacement member represents the longitudinally movable firing member, firing bar, I-beam, or combinations thereof.

A single revolution of the sensor element associated with the position sensor **472** is equivalent to a longitudinal linear displacement d1 of the of the displacement member, where d1 is the longitudinal linear distance that the displacement member moves from point "a" to point "b" after a single revolution of the sensor element coupled to the displacement member. The sensor arrangement may be connected via a gear reduction that results in the position sensor **472** completing one or more revolutions for the full stroke of the displacement member. The position sensor **472** may complete multiple revolutions for the full stroke of the displacement member.

A series of switches, where n is an integer greater than one, may be employed alone or in combination with a gear reduction to provide a unique position signal for more than one revolution of the position sensor **472**. The state of the switches are fed back to the microcontroller **461** that applies logic to determine a unique position signal corresponding to the longitudinal linear displacement d1+d2+ . . . dn of the displacement member. The output of the position sensor **472** is provided to the microcontroller **461**. The position sensor **472** of the sensor arrangement may comprise a magnetic sensor, an analog rotary sensor like a potentiometer, or an array of analog Hall-effect elements, which output a unique combination of position signals or values.

The position sensor **472** may comprise any number of magnetic sensing elements, such as, for example, magnetic sensors classified according to whether they measure the total magnetic field or the vector components of the magnetic field. The techniques used to produce both types of magnetic sensors encompass many aspects of physics and electronics. The technologies used for magnetic field sensing include search coil, fluxgate, optically pumped, nuclear precession, SQUID, Hall-effect, anisotropic magnetoresistance, giant magnetoresistance, magnetic tunnel junctions, giant magnetoimpedance, magnetostrictive/piezoelectric composites, magnetodiode, magnetotransistor, fiber-optic, magneto-optic, and microelectromechanical systems-based magnetic sensors, among others.

In one aspect, the position sensor **472** for the tracking system **480** comprising an absolute positioning system comprises a magnetic rotary absolute positioning system. The position sensor **472** may be implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **472** is interfaced with the microcontroller **461** to provide an absolute positioning system. The position sensor **472** is a low-voltage and low-power component and includes four Hall-effect elements in an area of the position sensor **472** that is located above a magnet. A high-resolution ADC and a smart power management controller are also provided on the chip. A coordinate rotation digital computer (CORDIC) processor, also known as the digit-by-digit method and Volder's algorithm, is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations. The angle position, alarm bits, and magnetic field information are trans-

mitted over a standard serial communication interface, such as a serial peripheral interface (SPI) interface, to the microcontroller **461**. The position sensor **472** provides 12 or 14 bits of resolution. The position sensor **472** may be an AS5055 chip provided in a small QFN 16-pin 4×4×0.85 mm package.

The tracking system **480** comprising an absolute positioning system may comprise and/or be programmed to implement a feedback controller, such as a PID, state feedback, and adaptive controller. A power source converts the signal from the feedback controller into a physical input to the system: in this case the voltage. Other examples include a PWM of the voltage, current, and force. Other sensor(s) may be provided to measure physical parameters of the physical system in addition to the position measured by the position sensor **472**. In some aspects, the other sensor(s) can include sensor arrangements such as those described in U.S. Pat. No. 9,345,481, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, which issued on May 24, 2016, which is herein incorporated by reference in its entirety; U.S. Patent Application Publication No. 2014/0263552, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, published on Sep. 18, 2014, which is herein incorporated by reference in its entirety; and U.S. patent application Ser. No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed Jun. 20, 2017, which is herein incorporated by reference in its entirety. In a digital signal processing system, an absolute positioning system is coupled to a digital data acquisition system where the output of the absolute positioning system will have a finite resolution and sampling frequency. The absolute positioning system may comprise a compare-and-combine circuit to combine a computed response with a measured response using algorithms, such as a weighted average and a theoretical control loop, that drive the computed response towards the measured response. The computed response of the physical system takes into account properties like mass, inertial, viscous friction, inductance resistance, etc., to predict what the states and outputs of the physical system will be by knowing the input.

The absolute positioning system provides an absolute position of the displacement member upon power-up of the instrument, without retracting or advancing the displacement member to a reset position (zero or home) as may be required with conventional rotary encoders that merely count the number of steps forwards or backwards that the motor **482** has taken to infer the position of a device actuator, drive bar, knife, or the like.

A sensor **474**, such as, for example, a strain gauge or a micro-strain gauge, is configured to measure one or more parameters of the end effector, such as, for example, the amplitude of the strain exerted on the anvil during a clamping operation, which can be indicative of the closure forces applied to the anvil. The measured strain is converted to a digital signal and provided to the processor **462**. Alternatively, or in addition to the sensor **474**, a sensor **476**, such as, for example, a load sensor, can measure the closure force applied by the closure drive system to the anvil. The sensor **476**, such as, for example, a load sensor, can measure the firing force applied to an I-beam in a firing stroke of the surgical instrument or tool. The I-beam is configured to engage a wedge sled, which is configured to upwardly cam staple drivers to force out staples into deforming contact with an anvil. The I-beam also includes a sharpened cutting edge that can be used to sever tissue as the I-beam is advanced distally by the firing bar. Alternatively, a current sensor **478** can be employed to measure the current drawn by the motor **482**. The force required to advance the firing member can correspond to the current drawn by the motor **482**, for example. The measured force is converted to a digital signal and provided to the processor **462**.

In one form, the strain gauge sensor **474** can be used to measure the force applied to the tissue by the end effector. A strain gauge can be coupled to the end effector to measure the force on the tissue being treated by the end effector. A system for measuring forces applied to the tissue grasped by the end effector comprises a strain gauge sensor **474**, such as, for example, a micro-strain gauge, that is configured to measure one or more parameters of the end effector, for example. In one aspect, the strain gauge sensor **474** can measure the amplitude or magnitude of the strain exerted on a jaw member of an end effector during a clamping operation, which can be indicative of the tissue compression. The measured strain is converted to a digital signal and provided to a processor **462** of the microcontroller **461**. A load sensor **476** can measure the force used to operate the knife element, for example, to cut the tissue captured between the anvil and the staple cartridge. A magnetic field sensor can be employed to measure the thickness of the captured tissue. The measurement of the magnetic field sensor also may be converted to a digital signal and provided to the processor **462**.

The measurements of the tissue compression, the tissue thickness, and/or the force required to close the end effector on the tissue, as respectively measured by the sensors **474**, **476**, can be used by the microcontroller **461** to characterize the selected position of the firing member and/or the corresponding value of the speed of the firing member. In one instance, a memory **468** may store a technique, an equation, and/or a lookup table which can be employed by the microcontroller **461** in the assessment.

The control system **470** of the surgical instrument or tool also may comprise wired or wireless communication circuits to communicate with the modular communication hub as shown in FIGS. **8-11**.

FIG. **13** illustrates a control circuit **500** configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The control circuit **500** can be configured to implement various processes described herein. The control circuit **500** may comprise a microcontroller comprising one or more processors **502** (e.g., microprocessor, microcontroller) coupled to at least one memory circuit **504**. The memory circuit **504** stores machine-executable instructions that, when executed by the processor **502**, cause the processor **502** to execute machine instructions to implement various processes described herein. The processor **502** may be any one of a number of single-core or multicore processors known in the art. The memory circuit **504** may comprise volatile and non-volatile storage media. The processor **502** may include an instruction processing unit **506** and an arithmetic unit **508**. The instruction processing unit may be configured to receive instructions from the memory circuit **504** of this disclosure.

FIG. **14** illustrates a combinational logic circuit **510** configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The combinational logic circuit **510** can be configured to implement various processes described herein. The combinational logic circuit **510** may comprise a finite state machine comprising a combinational logic **512** configured to receive data asso-

ciated with the surgical instrument or tool at an input **514**, process the data by the combinational logic **512**, and provide an output **516**.

FIG. **15** illustrates a sequential logic circuit **520** configured to control aspects of the surgical instrument or tool according to one aspect of this disclosure. The sequential logic circuit **520** or the combinational logic **522** can be configured to implement various processes described herein. The sequential logic circuit **520** may comprise a finite state machine. The sequential logic circuit **520** may comprise a combinational logic **522**, at least one memory circuit **524**, and a clock **529**, for example. The at least one memory circuit **524** can store a current state of the finite state machine. In certain instances, the sequential logic circuit **520** may be synchronous or asynchronous. The combinational logic **522** is configured to receive data associated with the surgical instrument or tool from an input **526**, process the data by the combinational logic **522**, and provide an output **528**. In other aspects, the circuit may comprise a combination of a processor (e.g., processor **502**, FIG. **13**) and a finite state machine to implement various processes herein. In other aspects, the finite state machine may comprise a combination of a combinational logic circuit (e.g., combinational logic circuit **510**, FIG. **14**) and the sequential logic circuit **520**.

FIG. **16** illustrates a surgical instrument or tool comprising a plurality of motors that can be activated to perform various functions. In certain instances, a first motor can be activated to perform a first function, a second motor can be activated to perform a second function, a third motor can be activated to perform a third function, a fourth motor can be activated to perform a fourth function, and so on. In certain instances, the plurality of motors of robotic surgical instrument **600** can be individually activated to cause firing, closure, and/or articulation motions in the end effector. The firing, closure, and/or articulation motions can be transmitted to the end effector through a shaft assembly, for example.

In certain instances, the surgical instrument system or tool may include a firing motor **602**. The firing motor **602** may be operably coupled to a firing motor drive assembly **604**, which can be configured to transmit firing motions, generated by the firing motor **602** to the end effector, in particular to displace the I-beam element. In certain instances, the firing motions generated by the firing motor **602** may cause the staples to be deployed from the staple cartridge into tissue captured by the end effector and/or the cutting edge of the I-beam element to be advanced to cut the captured tissue, for example. The I-beam element may be retracted by reversing the direction of the firing motor **602**.

In certain instances, the surgical instrument or tool may include a closure motor **603**. The closure motor **603** may be operably coupled to a closure motor drive assembly **605** which can be configured to transmit closure motions, generated by the motor **603** to the end effector, in particular to displace a closure tube to close the anvil and compress tissue between the anvil and the staple cartridge. The closure motions may cause the end effector to transition from an open configuration to an approximated configuration to capture tissue, for example. The end effector may be transitioned to an open position by reversing the direction of the motor **603**.

In certain instances, the surgical instrument or tool may include one or more articulation motors **606***a*, **606***b*, for example. The motors articulation **606***a*, **606***b* may be operably coupled to respective articulation motor drive assemblies **608***a*, **608***b*, which can be configured to transmit articulation motions generated by the articulation motors **606***a*, **606***b* to the end effector. In certain instances, the articulation motions may cause the end effector to articulate relative to the shaft, for example.

As described above, the surgical instrument or tool may include a plurality of motors that may be configured to perform various independent functions. In certain instances, the plurality of motors of the surgical instrument or tool can be individually or separately activated to perform one or more functions while the other motors remain inactive. For example, the articulation motors **606***a*, **606***b* can be activated to cause the end effector to be articulated while the firing motor **602** remains inactive. Alternatively, the firing motor **602** can be activated to fire the plurality of staples, and/or to advance the cutting edge, while the articulation motor **606** remains inactive. Furthermore the closure motor **603** may be activated simultaneously with the firing motor **602** to cause the closure tube and the I-beam element to advance distally as described in more detail hereinbelow.

In certain instances, the surgical instrument or tool may include a common control module **610**, which can be employed with a plurality of motors of the surgical instrument or tool. In certain instances, the common control module **610** may accommodate one of the plurality of motors at a time. For example, the common control module **610** can be couplable to and separable from the plurality of motors of the robotic surgical instrument individually. In certain instances, a plurality of the motors of the surgical instrument or tool may share one or more common control modules such as the common control module **610**. In certain instances, a plurality of motors of the surgical instrument or tool can be individually and selectively engaged with the common control module **610**. In certain instances, the common control module **610** can be selectively switched from interfacing with one of a plurality of motors of the surgical instrument or tool to interfacing with another one of the plurality of motors of the surgical instrument or tool.

In at least one example, the common control module **610** can be selectively switched between operable engagement with the articulation motors **606***a*, **606***b* and operable engagement with either the firing motor **602** or the closure motor **603**. In at least one example, as illustrated in FIG. **16**, a switch **614** can be moved or transitioned between a plurality of positions and/or states. In a first position **616**, the switch **614** may electrically couple the common control module **610** to the firing motor **602**; in a second position **617**, the switch **614** may electrically couple the common control module **610** to the closure motor **603**; in a third position **618***a*, the switch **614** may electrically couple the common control module **610** to the first articulation motor **606***a*; and in a fourth position **618***b*, the switch **614** may electrically couple the common control module **610** to the second articulation motor **606***b*, for example. In certain instances, separate common control modules **610** can be electrically coupled to the firing motor **602**, the closure motor **603**, and the articulation motors **606***a*, **606***b* at the same time. In certain instances, the switch **614** may be a mechanical switch, an electromechanical switch, a solid-state switch, or any suitable switching mechanism.

Each of the motors **602**, **603**, **606***a*, **606***b* may comprise a torque sensor to measure the output torque on the shaft of the motor. The force on an end effector may be sensed in any conventional manner, such as by force sensors on the outer sides of the jaws or by a torque sensor for the motor actuating the jaws.

In various instances, as illustrated in FIG. **16**, the common control module **610** may comprise a motor driver **626** which may comprise one or more H-Bridge FETs. The motor driver

626 may modulate the power transmitted from a power source 628 to a motor coupled to the common control module 610 based on input from a microcontroller 620 (the "controller"), for example. In certain instances, the microcontroller 620 can be employed to determine the current drawn by the motor, for example, while the motor is coupled to the common control module 610, as described above.

In certain instances, the microcontroller 620 may include a microprocessor 622 (the "processor") and one or more non-transitory computer-readable mediums or memory units 624 (the "memory"). In certain instances, the memory 624 may store various program instructions, which when executed may cause the processor 622 to perform a plurality of functions and/or calculations described herein. In certain instances, one or more of the memory units 624 may be coupled to the processor 622, for example.

In certain instances, the power source 628 can be employed to supply power to the microcontroller 620, for example. In certain instances, the power source 628 may comprise a battery (or "battery pack" or "power pack"), such as a lithium-ion battery, for example. In certain instances, the battery pack may be configured to be releasably mounted to a handle for supplying power to the surgical instrument 600. A number of battery cells connected in series may be used as the power source 628. In certain instances, the power source 628 may be replaceable and/or rechargeable, for example.

In various instances, the processor 622 may control the motor driver 626 to control the position, direction of rotation, and/or velocity of a motor that is coupled to the common control module 610. In certain instances, the processor 622 can signal the motor driver 626 to stop and/or disable a motor that is coupled to the common control module 610. It should be understood that the term "processor" as used herein includes any suitable microprocessor, microcontroller, or other basic computing device that incorporates the functions of a computer's central processing unit (CPU) on an integrated circuit or, at most, a few integrated circuits. The processor is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. Processors operate on numbers and symbols represented in the binary numeral system.

In one instance, the processor 622 may be any single-core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In certain instances, the microcontroller 620 may be an LM 4F230H5QR, available from Texas Instruments, for example. In at least one example, the Texas Instruments LM4F230H5QR is an ARM Cortex-M4F Processor Core comprising an on-chip memory of 256 KB single-cycle flash memory, or other NVM, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, an internal ROM loaded with StellarisWare® software, a 2 KB EEPROM, one or more PWM modules, one or more QEI analogs, one or more 12-bit ADCs with 12 analog input channels, among other features that are readily available for the product datasheet. Other microcontrollers may be readily substituted for use with the module 4410. Accordingly, the present disclosure should not be limited in this context.

In certain instances, the memory 624 may include program instructions for controlling each of the motors of the surgical instrument 600 that are couplable to the common control module 610. For example, the memory 624 may include program instructions for controlling the firing motor 602, the closure motor 603, and the articulation motors 606*a*, 606*b*. Such program instructions may cause the processor 622 to control the firing, closure, and articulation functions in accordance with inputs from algorithms or control programs of the surgical instrument or tool.

In certain instances, one or more mechanisms and/or sensors such as, for example, sensors 630 can be employed to alert the processor 622 to the program instructions that should be used in a particular setting. For example, the sensors 630 may alert the processor 622 to use the program instructions associated with firing, closing, and articulating the end effector. In certain instances, the sensors 630 may comprise position sensors which can be employed to sense the position of the switch 614, for example. Accordingly, the processor 622 may use the program instructions associated with firing the I-beam of the end effector upon detecting, through the sensors 630 for example, that the switch 614 is in the first position 616; the processor 622 may use the program instructions associated with closing the anvil upon detecting, through the sensors 630 for example, that the switch 614 is in the second position 617; and the processor 622 may use the program instructions associated with articulating the end effector upon detecting, through the sensors 630 for example, that the switch 614 is in the third or fourth positions 618*a*, 618*b*.

FIG. 17 is a schematic diagram of a robotic surgical instrument 700 configured to operate a surgical tool described herein according to one aspect of this disclosure. The robotic surgical instrument 700 may be programmed or configured to control distal/proximal translation of a displacement member, distal/proximal displacement of a closure tube, shaft rotation, and articulation, either with single or multiple articulation drive links. In one aspect, the surgical instrument 700 may be programmed or configured to individually control a firing member, a closure member, a shaft member, and/or one or more articulation members. The surgical instrument 700 comprises a control circuit 710 configured to control motor-driven firing members, closure members, shaft members, and/or one or more articulation members.

In one aspect, the robotic surgical instrument 700 comprises a control circuit 710 configured to control an anvil 716 and an I-beam 714 (including a sharp cutting edge) portion of an end effector 702, a removable staple cartridge 718, a shaft 740, and one or more articulation members 742*a*, 742*b* via a plurality of motors 704*a*-704*e*. A position sensor 734 may be configured to provide position feedback of the I-beam 714 to the control circuit 710. Other sensors 738 may be configured to provide feedback to the control circuit 710. A timer/counter 731 provides timing and counting information to the control circuit 710. An energy source 712 may be provided to operate the motors 704*a*-704*e*, and a current sensor 736 provides motor current feedback to the control circuit 710. The motors 704*a*-704*e* can be operated individually by the control circuit 710 in an open-loop or closed-loop feedback control.

In one aspect, the control circuit 710 may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to perform one or more tasks. In one aspect, a timer/counter 731 provides an output signal, such as the elapsed time or a digital count, to the control circuit 710 to correlate the position of the I-beam 714 as determined by the position sensor 734 with the output of the timer/counter 731 such that the control circuit 710 can determine the position of the I-beam 714 at a specific time (t) relative to a starting position or the time (t) when the I-beam 714 is

at a specific position relative to a starting position. The timer/counter **731** may be configured to measure elapsed time, count external events, or time external events.

In one aspect, the control circuit **710** may be programmed to control functions of the end effector **702** based on one or more tissue conditions. The control circuit **710** may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit **710** may be programmed to select a firing control program or closure control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit **710** may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit **710** may be programmed to translate the displacement member at a higher velocity and/or with higher power. A closure control program may control the closure force applied to the tissue by the anvil **716**. Other control programs control the rotation of the shaft **740** and the articulation members **742***a*, **742***b*.

In one aspect, the control circuit **710** may generate motor set point signals. The motor set point signals may be provided to various motor controllers **708***a*-**708***e*. The motor controllers **708***a*-**708***e* may comprise one or more circuits configured to provide motor drive signals to the motors **704***a*-**704***e* to drive the motors **704***a*-**704***e* as described herein. In some examples, the motors **704***a*-**704***e* may be brushed DC electric motors. For example, the velocity of the motors **704***a*-**704***e* may be proportional to the respective motor drive signals. In some examples, the motors **704***a*-**704***e* may be brushless DC electric motors, and the respective motor drive signals may comprise a PWM signal provided to one or more stator windings of the motors **704***a*-**704***e*. Also, in some examples, the motor controllers **708***a*-**708***e* may be omitted and the control circuit **710** may generate the motor drive signals directly.

In one aspect, the control circuit **710** may initially operate each of the motors **704***a*-**704***e* in an open-loop configuration for a first open-loop portion of a stroke of the displacement member. Based on the response of the robotic surgical instrument **700** during the open-loop portion of the stroke, the control circuit **710** may select a firing control program in a closed-loop configuration. The response of the instrument may include a translation distance of the displacement member during the open-loop portion, a time elapsed during the open-loop portion, the energy provided to one of the motors **704***a*-**704***e* during the open-loop portion, a sum of pulse widths of a motor drive signal, etc. After the open-loop portion, the control circuit **710** may implement the selected firing control program for a second portion of the displacement member stroke. For example, during a closed-loop portion of the stroke, the control circuit **710** may modulate one of the motors **704***a*-**704***e* based on translation data describing a position of the displacement member in a closed-loop manner to translate the displacement member at a constant velocity.

In one aspect, the motors **704***a*-**704***e* may receive power from an energy source **712**. The energy source **712** may be a DC power supply driven by a main alternating current power source, a battery, a super capacitor, or any other suitable energy source. The motors **704***a*-**704***e* may be mechanically coupled to individual movable mechanical elements such as the I-beam **714**, anvil **716**, shaft **740**, articulation **742***a*, and articulation **742***b* via respective transmissions **706***a*-**706***e*. The transmissions **706***a*-**706***e* may include one or more gears or other linkage components to couple the motors **704***a*-**704***e* to movable mechanical elements. A position sensor **734** may sense a position of the I-beam **714**. The position sensor **734** may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam **714**. In some examples, the position sensor **734** may include an encoder configured to provide a series of pulses to the control circuit **710** as the I-beam **714** translates distally and proximally. The control circuit **710** may track the pulses to determine the position of the I-beam **714**. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **714**. Also, in some examples, the position sensor **734** may be omitted. Where any of the motors **704***a*-**704***e* is a stepper motor, the control circuit **710** may track the position of the I-beam **714** by aggregating the number and direction of steps that the motor **704** has been instructed to execute. The position sensor **734** may be located in the end effector **702** or at any other portion of the instrument. The outputs of each of the motors **704***a*-**704***e* include a torque sensors **744***a*-**744***e* to sense force and have an encoder to sense rotation of the drive shaft.

In one aspect, the control circuit **710** is configured to drive a firing member such as the I-beam **714** portion of the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***a*, which provides a drive signal to the motor **704***a*. The output shaft of the motor **704***a* is coupled to a torque sensor **744***a*. The torque sensor **744***a* is coupled to a transmission **706***a*, which is coupled to the I-beam **714**. The transmission **706***a* comprises movable mechanical elements such as rotating elements and a firing member to control the movement of the I-beam **714** distally and proximally along a longitudinal axis of the end effector **702**. In one aspect, the motor **704***a* may be coupled to the knife gear assembly, which includes a knife gear reduction set that includes a first knife drive gear and a second knife drive gear. A torque sensor **744***a* provides a firing force feedback signal to the control circuit **710**. The firing force signal represents the force required to fire or displace the I-beam **714**. A position sensor **734** may be configured to provide the position of the I-beam **714** along the firing stroke or the position of the firing member as a feedback signal to the control circuit **710**. The end effector **702** may include additional sensors **738** configured to provide feedback signals to the control circuit **710**. When ready to use, the control circuit **710** may provide a firing signal to the motor control **708***a*. In response to the firing signal, the motor **704***a* may drive the firing member distally along the longitudinal axis of the end effector **702** from a proximal stroke start position to a stroke end position distal to the stroke start position. As the firing member translates distally, an I-beam **714**, with a cutting element positioned at a distal end, advances distally to cut tissue located between the staple cartridge **718** and the anvil **716**.

In one aspect, the control circuit **710** is configured to drive a closure member such as the anvil **716** portion of the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***b*, which provides a drive signal to the motor **704***b*. The output shaft of the motor **704***b* is coupled to a torque sensor **744***b*. The torque sensor **744***b* is coupled to a transmission **706***b* which is coupled to the anvil **716**. The transmission **706***b* comprises movable mechanical elements such as rotating elements and a closure member to control the movement of the anvil **716** from the open and closed positions. In one aspect, the motor **704***b* is coupled to

a closure gear assembly, which includes a closure reduction gear set that is supported in meshing engagement with the closure spur gear. The torque sensor **744***b* provides a closure force feedback signal to the control circuit **710**. The closure force feedback signal represents the closure force applied to the anvil **716**. The position sensor **734** may be configured to provide the position of the closure member as a feedback signal to the control circuit **710**. Additional sensors **738** in the end effector **702** may provide the closure force feedback signal to the control circuit **710**. The pivotable anvil **716** is positioned opposite the staple cartridge **718**. When ready to use, the control circuit **710** may provide a closure signal to the motor control **708***b*. In response to the closure signal, the motor **704***b* advances a closure member to grasp tissue between the anvil **716** and the staple cartridge **718**.

In one aspect, the control circuit **710** is configured to rotate a shaft member such as the shaft **740** to rotate the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***c*, which provides a drive signal to the motor **704***c*. The output shaft of the motor **704***c* is coupled to a torque sensor **744***c*. The torque sensor **744***c* is coupled to a transmission **706***c*, which is coupled to the shaft **740**. The transmission **706***c* comprises movable mechanical elements such as rotating elements to control the rotation of the shaft **740** clockwise or counterclockwise up to and over 360°. In one aspect, the motor **704***c* is coupled to the rotational transmission assembly, which includes a tube gear segment that is formed on (or attached to) the proximal end of the proximal closure tube for operable engagement by a rotational gear assembly that is operably supported on the tool mounting plate. The torque sensor **744***c* provides a rotation force feedback signal to the control circuit **710**. The rotation force feedback signal represents the rotation force applied to the shaft **740**. The position sensor **734** may be configured to provide the position of the closure member as a feedback signal to the control circuit **710**. Additional sensors **738** such as a shaft encoder may provide the rotational position of the shaft **740** to the control circuit **710**.

In one aspect, the control circuit **710** is configured to articulate the end effector **702**. The control circuit **710** provides a motor set point to a motor control **708***d*, which provides a drive signal to the motor **704***d*. The output shaft of the motor **704***d* is coupled to a torque sensor **744***d*. The torque sensor **744***d* is coupled to a transmission **706***d*, which is coupled to an articulation member **742***a*. The transmission **706***d* comprises movable mechanical elements such as articulation elements to control the articulation of the end effector **702**±65°. In one aspect, the motor **704***d* is coupled to an articulation nut, which is rotatably journaled on the proximal end portion of the distal spine portion and is rotatably driven thereon by an articulation gear assembly. The torque sensor **744***d* provides an articulation force feedback signal to the control circuit **710**. The articulation force feedback signal represents the articulation force applied to the end effector **702**. Sensors **738**, such as an articulation encoder, may provide the articulation position of the end effector **702** to the control circuit **710**.

In another aspect, the articulation function of the robotic surgical system **700** may comprise two articulation members, or links, **742***a*, **742***b*. These articulation members **742***a*, **742***b* are driven by separate disks on the robot interface (the rack), which are driven by the two motors **704***d*, **704***e*. When the separate firing motor **704***a* is provided, each of articulation links **742***a*, **742***b* can be antagonistically driven with respect to the other link in order to provide a resistive holding motion and a load to the head when it is not moving and to provide an articulation motion as the head is articulated. The articulation members **742***a*, **742***b* attach to the head at a fixed radius as the head is rotated. Accordingly, the mechanical advantage of the push-and-pull link changes as the head is rotated. This change in the mechanical advantage may be more pronounced with other articulation link drive systems.

In one aspect, the one or more motors **704***a*-**704***e* may comprise a brushed DC motor with a gearbox and mechanical links to a firing member, closure member, or articulation member. Another example includes electric motors **704***a*-**704***e* that operate the movable mechanical elements such as the displacement member, articulation links, closure tube, and shaft. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies, and friction on the physical system. Such outside influence can be referred to as drag, which acts in opposition to one of electric motors **704***a*-**704***e*. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

In one aspect, the position sensor **734** may be implemented as an absolute positioning system. In one aspect, the position sensor **734** may comprise a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **734** may interface with the control circuit **710** to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

In one aspect, the control circuit **710** may be in communication with one or more sensors **738**. The sensors **738** may be positioned on the end effector **702** and adapted to operate with the robotic surgical instrument **700** to measure the various derived parameters such as the gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **738** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a load cell, a pressure sensor, a force sensor, a torque sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **702**. The sensors **738** may include one or more sensors. The sensors **738** may be located on the staple cartridge **718** deck to determine tissue location using segmented electrodes. The torque sensors **744***a*-**744***e* may be configured to sense force such as firing force, closure force, and/or articulation force, among others. Accordingly, the control circuit **710** can sense (1) the closure load experienced by the distal closure tube and its position, (2) the firing member at the rack and its position, (3) what portion of the staple cartridge **718** has tissue on it, and (4) the load and position on both articulation rods.

In one aspect, the one or more sensors **738** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **716** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **738** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **716** and the staple cartridge **718**. The sensors **738** may be configured to detect impedance of a tissue section located between the anvil **716**

and the staple cartridge **718** that is indicative of the thickness and/or fullness of tissue located therebetween.

In one aspect, the sensors **738** may be implemented as one or more limit switches, electromechanical devices, solid-state switches, Hall-effect devices, magneto-resistive (MR) devices, giant magneto-resistive (GMR) devices, magnetometers, among others. In other implementations, the sensors **738** may be implemented as solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors **738** may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

In one aspect, the sensors **738** may be configured to measure forces exerted on the anvil **716** by the closure drive system. For example, one or more sensors **738** can be at an interaction point between the closure tube and the anvil **716** to detect the closure forces applied by the closure tube to the anvil **716**. The forces exerted on the anvil **716** can be representative of the tissue compression experienced by the tissue section captured between the anvil **716** and the staple cartridge **718**. The one or more sensors **738** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **716** by the closure drive system. The one or more sensors **738** may be sampled in real time during a clamping operation by the processor of the control circuit **710**. The control circuit **710** receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil **716**.

In one aspect, a current sensor **736** can be employed to measure the current drawn by each of the motors **704***a*-**704***e*. The force required to advance any of the movable mechanical elements such as the I-beam **714** corresponds to the current drawn by one of the motors **704***a*-**704***e*. The force is converted to a digital signal and provided to the control circuit **710**. The control circuit **710** can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam **714** in the end effector **702** at or near a target velocity. The robotic surgical instrument **700** can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, a linear-quadratic (LQR), and/or an adaptive controller, for example. The robotic surgical instrument **700** can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example. Additional details are disclosed in U.S. patent application Ser. No. 15/636,829, titled CLOSED LOOP VELOCITY CONTROL TECHNIQUES FOR ROBOTIC SURGICAL INSTRUMENT, filed Jun. 29, 2017, which is herein incorporated by reference in its entirety.

FIG. **18** illustrates a block diagram of a surgical instrument **750** programmed to control the distal translation of a displacement member according to one aspect of this disclosure. In one aspect, the surgical instrument **750** is programmed to control the distal translation of a displacement member such as the I-beam **764**. The surgical instrument **750** comprises an end effector **752** that may comprise an anvil **766**, an I-beam **764** (including a sharp cutting edge), and a removable staple cartridge **768**.

The position, movement, displacement, and/or translation of a linear displacement member, such as the I-beam **764**, can be measured by an absolute positioning system, sensor arrangement, and position sensor **784**. Because the I-beam **764** is coupled to a longitudinally movable drive member, the position of the I-beam **764** can be determined by measuring the position of the longitudinally movable drive member employing the position sensor **784**. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam **764** can be achieved by the position sensor **784** as described herein. A control circuit **760** may be programmed to control the translation of the displacement member, such as the I-beam **764**. The control circuit **760**, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam **764**, in the manner described. In one aspect, a timer/counter **781** provides an output signal, such as the elapsed time or a digital count, to the control circuit **760** to correlate the position of the I-beam **764** as determined by the position sensor **784** with the output of the timer/counter **781** such that the control circuit **760** can determine the position of the I-beam **764** at a specific time (t) relative to a starting position. The timer/counter **781** may be configured to measure elapsed time, count external events, or time external events.

The control circuit **760** may generate a motor set point signal **772**. The motor set point signal **772** may be provided to a motor controller **758**. The motor controller **758** may comprise one or more circuits configured to provide a motor drive signal **774** to the motor **754** to drive the motor **754** as described herein. In some examples, the motor **754** may be a brushed DC electric motor. For example, the velocity of the motor **754** may be proportional to the motor drive signal **774**. In some examples, the motor **754** may be a brushless DC electric motor and the motor drive signal **774** may comprise a PWM signal provided to one or more stator windings of the motor **754**. Also, in some examples, the motor controller **758** may be omitted, and the control circuit **760** may generate the motor drive signal **774** directly.

The motor **754** may receive power from an energy source **762**. The energy source **762** may be or include a battery, a super capacitor, or any other suitable energy source. The motor **754** may be mechanically coupled to the I-beam **764** via a transmission **756**. The transmission **756** may include one or more gears or other linkage components to couple the motor **754** to the I-beam **764**. A position sensor **784** may sense a position of the I-beam **764**. The position sensor **784** may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam **764**. In some examples, the position sensor **784** may include an encoder configured to provide a series of pulses to the control circuit **760** as the I-beam **764** translates distally and proximally. The control circuit **760** may track the pulses to determine the position of the I-beam **764**. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **764**. Also, in some examples, the position sensor **784** may be omitted. Where the motor **754** is a stepper motor, the control circuit **760** may track the position of the I-beam **764** by aggregating the number and direction of steps that the motor **754** has been instructed to execute. The position sensor **784** may be located in the end effector **752** or at any other portion of the instrument.

The control circuit **760** may be in communication with one or more sensors **788**. The sensors **788** may be positioned on the end effector **752** and adapted to operate with the

surgical instrument **750** to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **788** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **752**. The sensors **788** may include one or more sensors.

The one or more sensors **788** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **766** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **788** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **766** and the staple cartridge **768**. The sensors **788** may be configured to detect impedance of a tissue section located between the anvil **766** and the staple cartridge **768** that is indicative of the thickness and/or fullness of tissue located therebetween.

The sensors **788** may be configured to measure forces exerted on the anvil **766** by a closure drive system. For example, one or more sensors **788** can be at an interaction point between a closure tube and the anvil **766** to detect the closure forces applied by a closure tube to the anvil **766**. The forces exerted on the anvil **766** can be representative of the tissue compression experienced by the tissue section captured between the anvil **766** and the staple cartridge **768**. The one or more sensors **788** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **766** by the closure drive system. The one or more sensors **788** may be sampled in real time during a clamping operation by a processor of the control circuit **760**. The control circuit **760** receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil **766**.

A current sensor **786** can be employed to measure the current drawn by the motor **754**. The force required to advance the I-beam **764** corresponds to the current drawn by the motor **754**. The force is converted to a digital signal and provided to the control circuit **760**.

The control circuit **760** can be configured to simulate the response of the actual system of the instrument in the software of the controller. A displacement member can be actuated to move an I-beam **764** in the end effector **752** at or near a target velocity. The surgical instrument **750** can include a feedback controller, which can be one of any feedback controllers, including, but not limited to a PID, a state feedback, an LQR, and/or an adaptive controller, for example. The surgical instrument **750** can include a power source to convert the signal from the feedback controller into a physical input such as case voltage, PWM voltage, frequency modulated voltage, current, torque, and/or force, for example.

The actual drive system of the surgical instrument **750** is configured to drive the displacement member, cutting member, or I-beam **764**, by a brushed DC motor with gearbox and mechanical links to an articulation and/or knife system. Another example is the electric motor **754** that operates the displacement member and the articulation driver, for example, of an interchangeable shaft assembly. An outside influence is an unmeasured, unpredictable influence of things like tissue, surrounding bodies, and friction on the physical system. Such outside influence can be referred to as drag which acts in opposition to the electric motor **754**. The outside influence, such as drag, may cause the operation of the physical system to deviate from a desired operation of the physical system.

Various example aspects are directed to a surgical instrument **750** comprising an end effector **752** with motor-driven surgical stapling and cutting implements. For example, a motor **754** may drive a displacement member distally and proximally along a longitudinal axis of the end effector **752**. The end effector **752** may comprise a pivotable anvil **766** and, when configured for use, a staple cartridge **768** positioned opposite the anvil **766**. A clinician may grasp tissue between the anvil **766** and the staple cartridge **768**, as described herein. When ready to use the instrument **750**, the clinician may provide a firing signal, for example by depressing a trigger of the instrument **750**. In response to the firing signal, the motor **754** may drive the displacement member distally along the longitudinal axis of the end effector **752** from a proximal stroke begin position to a stroke end position distal of the stroke begin position. As the displacement member translates distally, an I-beam **764** with a cutting element positioned at a distal end, may cut the tissue between the staple cartridge **768** and the anvil **766**.

In various examples, the surgical instrument **750** may comprise a control circuit **760** programmed to control the distal translation of the displacement member, such as the I-beam **764**, for example, based on one or more tissue conditions. The control circuit **760** may be programmed to sense tissue conditions, such as thickness, either directly or indirectly, as described herein. The control circuit **760** may be programmed to select a firing control program based on tissue conditions. A firing control program may describe the distal motion of the displacement member. Different firing control programs may be selected to better treat different tissue conditions. For example, when thicker tissue is present, the control circuit **760** may be programmed to translate the displacement member at a lower velocity and/or with lower power. When thinner tissue is present, the control circuit **760** may be programmed to translate the displacement member at a higher velocity and/or with higher power.

In some examples, the control circuit **760** may initially operate the motor **754** in an open loop configuration for a first open loop portion of a stroke of the displacement member. Based on a response of the instrument **750** during the open loop portion of the stroke, the control circuit **760** may select a firing control program. The response of the instrument may include, a translation distance of the displacement member during the open loop portion, a time elapsed during the open loop portion, energy provided to the motor **754** during the open loop portion, a sum of pulse widths of a motor drive signal, etc. After the open loop portion, the control circuit **760** may implement the selected firing control program for a second portion of the displacement member stroke. For example, during the closed loop portion of the stroke, the control circuit **760** may modulate the motor **754** based on translation data describing a position of the displacement member in a closed loop manner to translate the displacement member at a constant velocity. Additional details are disclosed in U.S. patent application Ser. No. 15/720,852, titled SYSTEM AND METHODS FOR CONTROLLING A DISPLAY OF A SURGICAL INSTRUMENT, filed Sep. 29, 2017, which is herein incorporated by reference in its entirety.

FIG. **19** is a schematic diagram of a surgical instrument **790** configured to control various functions according to one aspect of this disclosure. In one aspect, the surgical instrument **790** is programmed to control distal translation of a

displacement member such as the I-beam **764**. The surgical instrument **790** comprises an end effector **792** that may comprise an anvil **766**, an I-beam **764**, and a removable staple cartridge **768**, which may be interchanged with an RF cartridge **796** (shown in dashed line).

In one aspect, sensors **788** may be implemented as a limit switch, electromechanical device, solid-state switches, Hall-effect devices, MR devices, GMR devices, magnetometers, among others. In other implementations, the sensors **638** may be solid-state switches that operate under the influence of light, such as optical sensors, IR sensors, ultraviolet sensors, among others. Still, the switches may be solid-state devices such as transistors (e.g., FET, junction FET, MOSFET, bipolar, and the like). In other implementations, the sensors **788** may include electrical conductorless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

In one aspect, the position sensor **784** may be implemented as an absolute positioning system comprising a magnetic rotary absolute positioning system implemented as an AS5055EQFT single-chip magnetic rotary position sensor available from Austria Microsystems, AG. The position sensor **784** may interface with the control circuit **760** to provide an absolute positioning system. The position may include multiple Hall-effect elements located above a magnet and coupled to a CORDIC processor, also known as the digit-by-digit method and Volder's algorithm, that is provided to implement a simple and efficient algorithm to calculate hyperbolic and trigonometric functions that require only addition, subtraction, bitshift, and table lookup operations.

In one aspect, the I-beam **764** may be implemented as a knife member comprising a knife body that operably supports a tissue cutting blade thereon and may further include anvil engagement tabs or features and channel engagement features or a foot. In one aspect, the staple cartridge **768** may be implemented as a standard (mechanical) surgical fastener cartridge. In one aspect, the RF cartridge **796** may be implemented as an RF cartridge. These and other sensors arrangements are described in commonly owned U.S. patent application Ser. No. 15/628,175, titled TECHNIQUES FOR ADAPTIVE CONTROL OF MOTOR VELOCITY OF A SURGICAL STAPLING AND CUTTING INSTRUMENT, filed Jun. 20, 2017, which is herein incorporated by reference in its entirety.

The position, movement, displacement, and/or translation of a linear displacement member, such as the I-beam **764**, can be measured by an absolute positioning system, sensor arrangement, and position sensor represented as position sensor **784**. Because the I-beam **764** is coupled to the longitudinally movable drive member, the position of the I-beam **764** can be determined by measuring the position of the longitudinally movable drive member employing the position sensor **784**. Accordingly, in the following description, the position, displacement, and/or translation of the I-beam **764** can be achieved by the position sensor **784** as described herein. A control circuit **760** may be programmed to control the translation of the displacement member, such as the I-beam **764**, as described herein. The control circuit **760**, in some examples, may comprise one or more microcontrollers, microprocessors, or other suitable processors for executing instructions that cause the processor or processors to control the displacement member, e.g., the I-beam **764**, in the manner described. In one aspect, a timer/counter **781** provides an output signal, such as the elapsed time or a digital count, to the control circuit **760** to correlate the position of the I-beam **764** as determined by the position sensor **784** with the output of the timer/counter **781** such that the control circuit **760** can determine the position of the I-beam **764** at a specific time (t) relative to a starting position. The timer/counter **781** may be configured to measure elapsed time, count external events, or time external events.

The control circuit **760** may generate a motor set point signal **772**. The motor set point signal **772** may be provided to a motor controller **758**. The motor controller **758** may comprise one or more circuits configured to provide a motor drive signal **774** to the motor **754** to drive the motor **754** as described herein. In some examples, the motor **754** may be a brushed DC electric motor. For example, the velocity of the motor **754** may be proportional to the motor drive signal **774**. In some examples, the motor **754** may be a brushless DC electric motor and the motor drive signal **774** may comprise a PWM signal provided to one or more stator windings of the motor **754**. Also, in some examples, the motor controller **758** may be omitted, and the control circuit **760** may generate the motor drive signal **774** directly.

The motor **754** may receive power from an energy source **762**. The energy source **762** may be or include a battery, a super capacitor, or any other suitable energy source. The motor **754** may be mechanically coupled to the I-beam **764** via a transmission **756**. The transmission **756** may include one or more gears or other linkage components to couple the motor **754** to the I-beam **764**. A position sensor **784** may sense a position of the I-beam **764**. The position sensor **784** may be or include any type of sensor that is capable of generating position data that indicate a position of the I-beam **764**. In some examples, the position sensor **784** may include an encoder configured to provide a series of pulses to the control circuit **760** as the I-beam **764** translates distally and proximally. The control circuit **760** may track the pulses to determine the position of the I-beam **764**. Other suitable position sensors may be used, including, for example, a proximity sensor. Other types of position sensors may provide other signals indicating motion of the I-beam **764**. Also, in some examples, the position sensor **784** may be omitted. Where the motor **754** is a stepper motor, the control circuit **760** may track the position of the I-beam **764** by aggregating the number and direction of steps that the motor has been instructed to execute. The position sensor **784** may be located in the end effector **792** or at any other portion of the instrument.

The control circuit **760** may be in communication with one or more sensors **788**. The sensors **788** may be positioned on the end effector **792** and adapted to operate with the surgical instrument **790** to measure the various derived parameters such as gap distance versus time, tissue compression versus time, and anvil strain versus time. The sensors **788** may comprise a magnetic sensor, a magnetic field sensor, a strain gauge, a pressure sensor, a force sensor, an inductive sensor such as an eddy current sensor, a resistive sensor, a capacitive sensor, an optical sensor, and/or any other suitable sensor for measuring one or more parameters of the end effector **792**. The sensors **788** may include one or more sensors.

The one or more sensors **788** may comprise a strain gauge, such as a micro-strain gauge, configured to measure the magnitude of the strain in the anvil **766** during a clamped condition. The strain gauge provides an electrical signal whose amplitude varies with the magnitude of the strain. The sensors **788** may comprise a pressure sensor configured to detect a pressure generated by the presence of compressed tissue between the anvil **766** and the staple cartridge **768**. The sensors **788** may be configured to detect impedance of

a tissue section located between the anvil **766** and the staple cartridge **768** that is indicative of the thickness and/or fullness of tissue located therebetween.

The sensors **788** may be configured to measure forces exerted on the anvil **766** by the closure drive system. For example, one or more sensors **788** can be at an interaction point between a closure tube and the anvil **766** to detect the closure forces applied by a closure tube to the anvil **766**. The forces exerted on the anvil **766** can be representative of the tissue compression experienced by the tissue section captured between the anvil **766** and the staple cartridge **768**. The one or more sensors **788** can be positioned at various interaction points along the closure drive system to detect the closure forces applied to the anvil **766** by the closure drive system. The one or more sensors **788** may be sampled in real time during a clamping operation by a processor portion of the control circuit **760**. The control circuit **760** receives real-time sample measurements to provide and analyze time-based information and assess, in real time, closure forces applied to the anvil **766**.

A current sensor **786** can be employed to measure the current drawn by the motor **754**. The force required to advance the I-beam **764** corresponds to the current drawn by the motor **754**. The force is converted to a digital signal and provided to the control circuit **760**.

An RF energy source **794** is coupled to the end effector **792** and is applied to the RF cartridge **796** when the RF cartridge **796** is loaded in the end effector **792** in place of the staple cartridge **768**. The control circuit **760** controls the delivery of the RF energy to the RF cartridge **796**.

Additional details are disclosed in U.S. patent application Ser. No. 15/636,096, titled SURGICAL SYSTEM COUPLABLE WITH STAPLE CARTRIDGE AND RADIO FREQUENCY CARTRIDGE, AND METHOD OF USING SAME, filed Jun. 28, 2017, which is herein incorporated by reference in its entirety.

FIG. **20** is a simplified block diagram of a generator **800** configured to provide inductorless tuning, among other benefits. Additional details of the generator **800** are described in U.S. Pat. No. 9,060,775, titled SURGICAL GENERATOR FOR ULTRASONIC AND ELECTROSURGICAL DEVICES, which issued on Jun. 23, 2015, which is herein incorporated by reference in its entirety. The generator **800** may comprise a patient isolated stage **802** in communication with a non-isolated stage **804** via a power transformer **806**. A secondary winding **808** of the power transformer **806** is contained in the isolated stage **802** and may comprise a tapped configuration (e.g., a center-tapped or a non-center-tapped configuration) to define drive signal outputs **810***a*, **810***b*, **810***c* for delivering drive signals to different surgical instruments, such as, for example, an ultrasonic surgical instrument, an RF electrosurgical instrument, and a multifunction surgical instrument, which includes ultrasonic and RF energy modes that can be delivered alone or simultaneously. In particular, drive signal outputs **810***a*, **810***c* may output an ultrasonic drive signal (e.g., a 420V root-mean-square (RMS) drive signal) to an ultrasonic surgical instrument, and drive signal outputs **810***b*, **810***c* may output an RF electrosurgical drive signal (e.g., a 100V RMS drive signal) to an RF electrosurgical instrument, with the drive signal output **810***b* corresponding to the center tap of the power transformer **806**.

In certain forms, the ultrasonic and electrosurgical drive signals may be provided simultaneously to distinct surgical instruments and/or to a single surgical instrument, such as the multifunction surgical instrument, having the capability to deliver both ultrasonic and electrosurgical energy to tissue. It will be appreciated that the electrosurgical signal, provided either to a dedicated electrosurgical instrument and/or to a combined multifunction ultrasonic/electrosurgical instrument may be either a therapeutic or sub-therapeutic level signal where the sub-therapeutic signal can be used, for example, to monitor tissue or instrument conditions and provide feedback to the generator. For example, the ultrasonic and RF signals can be delivered separately or simultaneously from a generator with a single output port in order to provide the desired output signal to the surgical instrument, as will be discussed in more detail below. Accordingly, the generator can combine the ultrasonic and electrosurgical RF energies and deliver the combined energies to the multifunction ultrasonic/electrosurgical instrument. Bipolar electrodes can be placed on one or both jaws of the end effector. One jaw may be driven by ultrasonic energy in addition to electrosurgical RF energy, working simultaneously. The ultrasonic energy may be employed to dissect tissue, while the electrosurgical RF energy may be employed for vessel sealing.

The non-isolated stage **804** may comprise a power amplifier **812** having an output connected to a primary winding **814** of the power transformer **806**. In certain forms, the power amplifier **812** may comprise a push-pull amplifier. For example, the non-isolated stage **804** may further comprise a logic device **816** for supplying a digital output to a digital-to-analog converter (DAC) circuit **818**, which in turn supplies a corresponding analog signal to an input of the power amplifier **812**. In certain forms, the logic device **816** may comprise a programmable gate array (PGA), a field programmable gate array (FPGA), programmable logic device (PLD), among other logic circuits, for example. The logic device **816**, by virtue of controlling the input of the power amplifier **812** via the DAC circuit **818**, may therefore control any of a number of parameters (e.g., frequency, waveform shape, waveform amplitude) of drive signals appearing at the drive signal outputs **810***a*, **810***b*, **810***c*. In certain forms and as discussed below, the logic device **816**, in conjunction with a processor (e.g., a DSP discussed below), may implement a number of DSP-based and/or other control algorithms to control parameters of the drive signals output by the generator **800**.

Power may be supplied to a power rail of the power amplifier **812** by a switch-mode regulator **820**, e.g., a power converter. In certain forms, the switch-mode regulator **820** may comprise an adjustable buck regulator, for example. The non-isolated stage **804** may further comprise a first processor **822**, which in one form may comprise a DSP processor such as an Analog Devices ADSP-21469 SHARC DSP, available from Analog Devices, Norwood, MA, for example, although in various forms any suitable processor may be employed. In certain forms the DSP processor **822** may control the operation of the switch-mode regulator **820** responsive to voltage feedback data received from the power amplifier **812** by the DSP processor **822** via an ADC circuit **824**. In one form, for example, the DSP processor **822** may receive as input, via the ADC circuit **824**, the waveform envelope of a signal (e.g., an RF signal) being amplified by the power amplifier **812**. The DSP processor **822** may then control the switch-mode regulator **820** (e.g., via a PWM output) such that the rail voltage supplied to the power amplifier **812** tracks the waveform envelope of the amplified signal. By dynamically modulating the rail voltage of the power amplifier **812** based on the waveform envelope, the efficiency of the power amplifier **812** may be significantly improved relative to a fixed rail voltage amplifier schemes.

In certain forms, the logic device **816**, in conjunction with the DSP processor **822**, may implement a digital synthesis circuit such as a direct digital synthesizer control scheme to control the waveform shape, frequency, and/or amplitude of drive signals output by the generator **800**. In one form, for example, the logic device **816** may implement a DDS control algorithm by recalling waveform samples stored in a dynamically updated lookup table (LUT), such as a RAM LUT, which may be embedded in an FPGA. This control algorithm is particularly useful for ultrasonic applications in which an ultrasonic transducer, such as an ultrasonic transducer, may be driven by a clean sinusoidal current at its resonant frequency. Because other frequencies may excite parasitic resonances, minimizing or reducing the total distortion of the motional branch current may correspondingly minimize or reduce undesirable resonance effects. Because the waveform shape of a drive signal output by the generator **800** is impacted by various sources of distortion present in the output drive circuit (e.g., the power transformer **806**, the power amplifier **812**), voltage and current feedback data based on the drive signal may be input into an algorithm, such as an error control algorithm implemented by the DSP processor **822**, which compensates for distortion by suitably pre-distorting or modifying the waveform samples stored in the LUT on a dynamic, ongoing basis (e.g., in real time). In one form, the amount or degree of pre-distortion applied to the LUT samples may be based on the error between a computed motional branch current and a desired current waveform shape, with the error being determined on a sample-by-sample basis. In this way, the pre-distorted LUT samples, when processed through the drive circuit, may result in a motional branch drive signal having the desired waveform shape (e.g., sinusoidal) for optimally driving the ultrasonic transducer. In such forms, the LUT waveform samples will therefore not represent the desired waveform shape of the drive signal, but rather the waveform shape that is required to ultimately produce the desired waveform shape of the motional branch drive signal when distortion effects are taken into account.

The non-isolated stage **804** may further comprise a first ADC circuit **826** and a second ADC circuit **828** coupled to the output of the power transformer **806** via respective isolation transformers **830**, **832** for respectively sampling the voltage and current of drive signals output by the generator **800**. In certain forms, the ADC circuits **826**, **828** may be configured to sample at high speeds (e.g., 80 mega samples per second (MSPS)) to enable oversampling of the drive signals. In one form, for example, the sampling speed of the ADC circuits **826**, **828** may enable approximately 200× (depending on frequency) oversampling of the drive signals. In certain forms, the sampling operations of the ADC circuit **826**, **828** may be performed by a single ADC circuit receiving input voltage and current signals via a two-way multiplexer. The use of high-speed sampling in forms of the generator **800** may enable, among other things, calculation of the complex current flowing through the motional branch (which may be used in certain forms to implement DDS-based waveform shape control described above), accurate digital filtering of the sampled signals, and calculation of real power consumption with a high degree of precision. Voltage and current feedback data output by the ADC circuits **826**, **828** may be received and processed (e.g., first-in-first-out (FIFO) buffer, multiplexer) by the logic device **816** and stored in data memory for subsequent retrieval by, for example, the DSP processor **822**. As noted above, voltage and current feedback data may be used as input to an algorithm for pre-distorting or modifying LUT waveform samples on a dynamic and ongoing basis. In certain forms, this may require each stored voltage and current feedback data pair to be indexed based on, or otherwise associated with, a corresponding LUT sample that was output by the logic device **816** when the voltage and current feedback data pair was acquired. Synchronization of the LUT samples and the voltage and current feedback data in this manner contributes to the correct timing and stability of the pre-distortion algorithm.

In certain forms, the voltage and current feedback data may be used to control the frequency and/or amplitude (e.g., current amplitude) of the drive signals. In one form, for example, voltage and current feedback data may be used to determine impedance phase. The frequency of the drive signal may then be controlled to minimize or reduce the difference between the determined impedance phase and an impedance phase setpoint (e.g., **00**), thereby minimizing or reducing the effects of harmonic distortion and correspondingly enhancing impedance phase measurement accuracy. The determination of phase impedance and a frequency control signal may be implemented in the DSP processor **822**, for example, with the frequency control signal being supplied as input to a DDS control algorithm implemented by the logic device **816**.

In another form, for example, the current feedback data may be monitored in order to maintain the current amplitude of the drive signal at a current amplitude setpoint. The current amplitude setpoint may be specified directly or determined indirectly based on specified voltage amplitude and power setpoints. In certain forms, control of the current amplitude may be implemented by control algorithm, such as, for example, a proportional-integral-derivative (PID) control algorithm, in the DSP processor **822**. Variables controlled by the control algorithm to suitably control the current amplitude of the drive signal may include, for example, the scaling of the LUT waveform samples stored in the logic device **816** and/or the full-scale output voltage of the DAC circuit **818** (which supplies the input to the power amplifier **812**) via a DAC circuit **834**.

The non-isolated stage **804** may further comprise a second processor **836** for providing, among other things user interface (UI) functionality. In one form, the UI processor **836** may comprise an Atmel AT91SAM9263 processor having an ARM 926EJ-S core, available from Atmel Corporation, San Jose, California, for example. Examples of UI functionality supported by the UI processor **836** may include audible and visual user feedback, communication with peripheral devices (e.g., via a USB interface), communication with a foot switch, communication with an input device (e.g., a touch screen display), and communication with an output device (e.g., a speaker). The UI processor **836** may communicate with the DSP processor **822** and the logic device **816** (e.g., via SPI buses). Although the UI processor **836** may primarily support UI functionality, it may also coordinate with the DSP processor **822** to implement hazard mitigation in certain forms. For example, the UI processor **836** may be programmed to monitor various aspects of user input and/or other inputs (e.g., touch screen inputs, foot switch inputs, temperature sensor inputs) and may disable the drive output of the generator **800** when an erroneous condition is detected.

In certain forms, both the DSP processor **822** and the UI processor **836**, for example, may determine and monitor the operating state of the generator **800**. For the DSP processor **822**, the operating state of the generator **800** may dictate, for example, which control and/or diagnostic processes are implemented by the DSP processor **822**. For the UI proces-

sor **836**, the operating state of the generator **800** may dictate, for example, which elements of a UI (e.g., display screens, sounds) are presented to a user. The respective DSP and UI processors **822**, **836** may independently maintain the current operating state of the generator **800** and recognize and evaluate possible transitions out of the current operating state. The DSP processor **822** may function as the master in this relationship and determine when transitions between operating states are to occur. The UI processor **836** may be aware of valid transitions between operating states and may confirm if a particular transition is appropriate. For example, when the DSP processor **822** instructs the UI processor **836** to transition to a specific state, the UI processor **836** may verify that requested transition is valid. In the event that a requested transition between states is determined to be invalid by the UI processor **836**, the UI processor **836** may cause the generator **800** to enter a failure mode.

The non-isolated stage **804** may further comprise a controller **838** for monitoring input devices (e.g., a capacitive touch sensor used for turning the generator **800** on and off, a capacitive touch screen). In certain forms, the controller **838** may comprise at least one processor and/or other controller device in communication with the UI processor **836**. In one form, for example, the controller **838** may comprise a processor (e.g., a Meg168 8-bit controller available from Atmel) configured to monitor user input provided via one or more capacitive touch sensors. In one form, the controller **838** may comprise a touch screen controller (e.g., a QT5480 touch screen controller available from Atmel) to control and manage the acquisition of touch data from a capacitive touch screen.

In certain forms, when the generator **800** is in a "power off" state, the controller **838** may continue to receive operating power (e.g., via a line from a power supply of the generator **800**, such as the power supply **854** discussed below). In this way, the controller **838** may continue to monitor an input device (e.g., a capacitive touch sensor located on a front panel of the generator **800**) for turning the generator **800** on and off. When the generator **800** is in the power off state, the controller **838** may wake the power supply (e.g., enable operation of one or more DC/DC voltage converters **856** of the power supply **854**) if activation of the "on/off" input device by a user is detected. The controller **838** may therefore initiate a sequence for transitioning the generator **800** to a "power on" state. Conversely, the controller **838** may initiate a sequence for transitioning the generator **800** to the power off state if activation of the "on/off" input device is detected when the generator **800** is in the power on state. In certain forms, for example, the controller **838** may report activation of the "on/off" input device to the UI processor **836**, which in turn implements the necessary process sequence for transitioning the generator **800** to the power off state. In such forms, the controller **838** may have no independent ability for causing the removal of power from the generator **800** after its power on state has been established.

In certain forms, the controller **838** may cause the generator **800** to provide audible or other sensory feedback for alerting the user that a power on or power off sequence has been initiated. Such an alert may be provided at the beginning of a power on or power off sequence and prior to the commencement of other processes associated with the sequence.

In certain forms, the isolated stage **802** may comprise an instrument interface circuit **840** to, for example, provide a communication interface between a control circuit of a surgical instrument (e.g., a control circuit comprising handpiece switches) and components of the non-isolated stage **804**, such as, for example, the logic device **816**, the DSP processor **822**, and/or the UI processor **836**. The instrument interface circuit **840** may exchange information with components of the non-isolated stage **804** via a communication link that maintains a suitable degree of electrical isolation between the isolated and non-isolated stages **802**, **804**, such as, for example, an IR-based communication link. Power may be supplied to the instrument interface circuit **840** using, for example, a low-dropout voltage regulator powered by an isolation transformer driven from the non-isolated stage **804**.

In one form, the instrument interface circuit **840** may comprise a logic circuit **842** (e.g., logic circuit, programmable logic circuit, PGA, FPGA, PLD) in communication with a signal conditioning circuit **844**. The signal conditioning circuit **844** may be configured to receive a periodic signal from the logic circuit **842** (e.g., a 2 kHz square wave) to generate a bipolar interrogation signal having an identical frequency. The interrogation signal may be generated, for example, using a bipolar current source fed by a differential amplifier. The interrogation signal may be communicated to a surgical instrument control circuit (e.g., by using a conductive pair in a cable that connects the generator **800** to the surgical instrument) and monitored to determine a state or configuration of the control circuit. The control circuit may comprise a number of switches, resistors, and/or diodes to modify one or more characteristics (e.g., amplitude, rectification) of the interrogation signal such that a state or configuration of the control circuit is uniquely discernable based on the one or more characteristics. In one form, for example, the signal conditioning circuit **844** may comprise an ADC circuit for generating samples of a voltage signal appearing across inputs of the control circuit resulting from passage of interrogation signal therethrough. The logic circuit **842** (or a component of the non-isolated stage **804**) may then determine the state or configuration of the control circuit based on the ADC circuit samples.

In one form, the instrument interface circuit **840** may comprise a first data circuit interface (DCI) **846** to enable information exchange between the logic circuit **842** (or other element of the instrument interface circuit **840**) and a first data circuit disposed in or otherwise associated with a surgical instrument. In certain forms, for example, a first data circuit may be disposed in a cable integrally attached to a surgical instrument handpiece or in an adaptor for interfacing a specific surgical instrument type or model with the generator **800**. The first data circuit may be implemented in any suitable manner and may communicate with the generator according to any suitable protocol, including, for example, as described herein with respect to the first data circuit. In certain forms, the first data circuit may comprise a non-volatile storage device, such as an EEPROM device. In certain forms, the first data circuit interface **846** may be implemented separately from the logic circuit **842** and comprise suitable circuitry (e.g., discrete logic devices, a processor) to enable communication between the logic circuit **842** and the first data circuit. In other forms, the first data circuit interface **846** may be integral with the logic circuit **842**.

In certain forms, the first data circuit may store information pertaining to the particular surgical instrument with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical instrument has been used, and/or any other type of information. This information may be read by the instrument interface circuit **840** (e.g., by the

logic circuit **842**), transferred to a component of the non-isolated stage **804** (e.g., to logic device **816**, DSP processor **822**, and/or UI processor **836**) for presentation to a user via an output device and/or for controlling a function or operation of the generator **800**. Additionally, any type of information may be communicated to the first data circuit for storage therein via the first data circuit interface **846** (e.g., using the logic circuit **842**). Such information may comprise, for example, an updated number of operations in which the surgical instrument has been used and/or dates and/or times of its usage.

As discussed previously, a surgical instrument may be detachable from a handpiece (e.g., the multifunction surgical instrument may be detachable from the handpiece) to promote instrument interchangeability and/or disposability. In such cases, conventional generators may be limited in their ability to recognize particular instrument configurations being used and to optimize control and diagnostic processes accordingly. The addition of readable data circuits to surgical instruments to address this issue is problematic from a compatibility standpoint, however. For example, designing a surgical instrument to remain backwardly compatible with generators that lack the requisite data reading functionality may be impractical due to, for example, differing signal schemes, design complexity, and cost. Forms of instruments discussed herein address these concerns by using data circuits that may be implemented in existing surgical instruments economically and with minimal design changes to preserve compatibility of the surgical instruments with current generator platforms.

Additionally, forms of the generator **800** may enable communication with instrument-based data circuits. For example, the generator **800** may be configured to communicate with a second data circuit contained in an instrument (e.g., the multifunction surgical instrument). In some forms, the second data circuit may be implemented in a many similar to that of the first data circuit described herein. The instrument interface circuit **840** may comprise a second data circuit interface **848** to enable this communication. In one form, the second data circuit interface **848** may comprise a tri-state digital interface, although other interfaces may also be used. In certain forms, the second data circuit may generally be any circuit for transmitting and/or receiving data. In one form, for example, the second data circuit may store information pertaining to the particular surgical instrument with which it is associated. Such information may include, for example, a model number, a serial number, a number of operations in which the surgical instrument has been used, and/or any other type of information.

In some forms, the second data circuit may store information about the electrical and/or ultrasonic properties of an associated ultrasonic transducer, end effector, or ultrasonic drive system. For example, the first data circuit may indicate a burn-in frequency slope, as described herein. Additionally or alternatively, any type of information may be communicated to second data circuit for storage therein via the second data circuit interface **848** (e.g., using the logic circuit **842**). Such information may comprise, for example, an updated number of operations in which the instrument has been used and/or dates and/or times of its usage. In certain forms, the second data circuit may transmit data acquired by one or more sensors (e.g., an instrument-based temperature sensor). In certain forms, the second data circuit may receive data from the generator **800** and provide an indication to a user (e.g., a light emitting diode indication or other visible indication) based on the received data.

In certain forms, the second data circuit and the second data circuit interface **848** may be configured such that communication between the logic circuit **842** and the second data circuit can be effected without the need to provide additional conductors for this purpose (e.g., dedicated conductors of a cable connecting a handpiece to the generator **800**). In one form, for example, information may be communicated to and from the second data circuit using a one-wire bus communication scheme implemented on existing cabling, such as one of the conductors used transmit interrogation signals from the signal conditioning circuit **844** to a control circuit in a handpiece. In this way, design changes or modifications to the surgical instrument that might otherwise be necessary are minimized or reduced. Moreover, because different types of communications implemented over a common physical channel can be frequency-band separated, the presence of a second data circuit may be "invisible" to generators that do not have the requisite data reading functionality, thus enabling backward compatibility of the surgical instrument.

In certain forms, the isolated stage **802** may comprise at least one blocking capacitor **850-1** connected to the drive signal output **810***b* to prevent passage of DC current to a patient. A single blocking capacitor may be required to comply with medical regulations or standards, for example. While failure in single-capacitor designs is relatively uncommon, such failure may nonetheless have negative consequences. In one form, a second blocking capacitor **850-2** may be provided in series with the blocking capacitor **850-1**, with current leakage from a point between the blocking capacitors **850-1**, **850-2** being monitored by, for example, an ADC circuit **852** for sampling a voltage induced by leakage current. The samples may be received by the logic circuit **842**, for example. Based changes in the leakage current (as indicated by the voltage samples), the generator **800** may determine when at least one of the blocking capacitors **850-1**, **850-2** has failed, thus providing a benefit over single-capacitor designs having a single point of failure.

In certain forms, the non-isolated stage **804** may comprise a power supply **854** for delivering DC power at a suitable voltage and current. The power supply may comprise, for example, a 400 W power supply for delivering a 48 VDC system voltage. The power supply **854** may further comprise one or more DC/DC voltage converters **856** for receiving the output of the power supply to generate DC outputs at the voltages and currents required by the various components of the generator **800**. As discussed above in connection with the controller **838**, one or more of the DC/DC voltage converters **856** may receive an input from the controller **838** when activation of the "on/off" input device by a user is detected by the controller **838** to enable operation of, or wake, the DC/DC voltage converters **856**.

FIG. **21** illustrates an example of a generator **900**, which is one form of the generator **800** (FIG. **20**). The generator **900** is configured to deliver multiple energy modalities to a surgical instrument. The generator **900** provides RF and ultrasonic signals for delivering energy to a surgical instrument either independently or simultaneously. The RF and ultrasonic signals may be provided alone or in combination and may be provided simultaneously. As noted above, at least one generator output can deliver multiple energy modalities (e.g., ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others) through a single port, and these signals can be delivered separately or simultaneously to the end effector to treat tissue.

The generator **900** comprises a processor **902** coupled to a waveform generator **904**. The processor **902** and waveform generator **904** are configured to generate a variety of signal waveforms based on information stored in a memory coupled to the processor **902**, not shown for clarity of disclosure. The digital information associated with a waveform is provided to the waveform generator **904** which includes one or more DAC circuits to convert the digital input into an analog output. The analog output is fed to an amplifier **1106** for signal conditioning and amplification. The conditioned and amplified output of the amplifier **906** is coupled to a power transformer **908**. The signals are coupled across the power transformer **908** to the secondary side, which is in the patient isolation side. A first signal of a first energy modality is provided to the surgical instrument between the terminals labeled $ENERGY_1$ and RETURN. A second signal of a second energy modality is coupled across a capacitor **910** and is provided to the surgical instrument between the terminals labeled $ENERGY_2$ and RETURN. It will be appreciated that more than two energy modalities may be output and thus the subscript "n" may be used to designate that up to n ENERGYn terminals may be provided, where n is a positive integer greater than 1. It also will be appreciated that up to "n" return paths RETURNn may be provided without departing from the scope of the present disclosure.

A first voltage sensing circuit **912** is coupled across the terminals labeled $ENERGY_1$ and the RETURN path to measure the output voltage therebetween. A second voltage sensing circuit **924** is coupled across the terminals labeled $ENERGY_2$ and the RETURN path to measure the output voltage therebetween. A current sensing circuit **914** is disposed in series with the RETURN leg of the secondary side of the power transformer **908** as shown to measure the output current for either energy modality. If different return paths are provided for each energy modality, then a separate current sensing circuit should be provided in each return leg. The outputs of the first and second voltage sensing circuits **912**, **924** are provided to respective isolation transformers **916**, **922** and the output of the current sensing circuit **914** is provided to another isolation transformer **918**. The outputs of the isolation transformers **916**, **928**, **922** in the on the primary side of the power transformer **908** (non-patient isolated side) are provided to a one or more ADC circuit **926**. The digitized output of the ADC circuit **926** is provided to the processor **902** for further processing and computation. The output voltages and output current feedback information can be employed to adjust the output voltage and current provided to the surgical instrument and to compute output impedance, among other parameters. Input/output communications between the processor **902** and patient isolated circuits is provided through an interface circuit **920**. Sensors also may be in electrical communication with the processor **902** by way of the interface circuit **920**.

In one aspect, the impedance may be determined by the processor **902** by dividing the output of either the first voltage sensing circuit **912** coupled across the terminals labeled $ENERGY_1$/RETURN or the second voltage sensing circuit **924** coupled across the terminals labeled $ENERGY_2$/RETURN by the output of the current sensing circuit **914** disposed in series with the RETURN leg of the secondary side of the power transformer **908**. The outputs of the first and second voltage sensing circuits **912**, **924** are provided to separate isolations transformers **916**, **922** and the output of the current sensing circuit **914** is provided to another isolation transformer **916**. The digitized voltage and current sensing measurements from the ADC circuit **926** are provided the processor **902** for computing impedance. As an example, the first energy modality $ENERGY_1$ may be ultrasonic energy and the second energy modality $ENERGY_2$ may be RF energy. Nevertheless, in addition to ultrasonic and bipolar or monopolar RF energy modalities, other energy modalities include irreversible and/or reversible electroporation and/or microwave energy, among others. Also, although the example illustrated in FIG. **21** shows a single return path RETURN may be provided for two or more energy modalities, in other aspects, multiple return paths RETURNn may be provided for each energy modality ENERGYn. Thus, as described herein, the ultrasonic transducer impedance may be measured by dividing the output of the first voltage sensing circuit **912** by the current sensing circuit **914** and the tissue impedance may be measured by dividing the output of the second voltage sensing circuit **924** by the current sensing circuit **914**.

As shown in FIG. **21**, the generator **900** comprising at least one output port can include a power transformer **908** with a single output and with multiple taps to provide power in the form of one or more energy modalities, such as ultrasonic, bipolar or monopolar RF, irreversible and/or reversible electroporation, and/or microwave energy, among others, for example, to the end effector depending on the type of treatment of tissue being performed. For example, the generator **900** can deliver energy with higher voltage and lower current to drive an ultrasonic transducer, with lower voltage and higher current to drive RF electrodes for sealing tissue, or with a coagulation waveform for spot coagulation using either monopolar or bipolar RF electrosurgical electrodes. The output waveform from the generator **900** can be steered, switched, or filtered to provide the frequency to the end effector of the surgical instrument. The connection of an ultrasonic transducer to the generator **900** output would be preferably located between the output labeled $ENERGY_1$ and RETURN as shown in FIG. **21**. In one example, a connection of RF bipolar electrodes to the generator **900** output would be preferably located between the output labeled $ENERGY_2$ and RETURN. In the case of monopolar output, the preferred connections would be active electrode (e.g., pencil or other probe) to the $ENERGY_2$ output and a suitable return pad connected to the RETURN output.

Additional details are disclosed in U.S. Patent Application Publication No. 2017/0086914, titled TECHNIQUES FOR OPERATING GENERATOR FOR DIGITALLY GENERATING ELECTRICAL SIGNAL WAVEFORMS AND SURGICAL INSTRUMENTS, which published on Mar. 30, 2017, which is herein incorporated by reference in its entirety.

FIG. **22** illustrates a surgical instrument **29000**, in accordance with at least one aspect of the present disclosure. For the aspects shown in FIG. **22**, the surgical instrument includes a handle **29002**, a bendable shaft assembly **29004**, an end effector **29006**, a motor (not visible through the outer surface of the handle **29002**) and a flexible circuit **29008**. Although the surgical instrument **29000** is shown in FIG. **22** as having a bendable shaft assembly **29004**, it will be appreciated that according to other aspects, the surgical instrument **29000** may include a shaft assembly having an articulation joint in lieu of the bendable portion.

FIG. **23** illustrates a shaft assembly **29005** of the surgical instrument **29000**, in accordance with at least one other aspect of the present disclosure. As shown in FIG. **23**, the shaft assembly **29005** includes an articulation joint **29010** and is coupled to the end effector **29006** which includes a first jaw **29012** and a second jaw **29014**, where at least one of the first and second jaws **29012**, **29014** is configured to

pivot between an open position and a closed position to clamp tissue between the first and second jaws **29012**, **29014**. Although the end effector **29006** is shown as including a staple cartridge **29016**, it will be appreciated that according to other aspects, the end effector **29006** may include electrodes in lieu of or in addition to the staple cartridge **29016**.

FIG. **24** illustrates the flexible circuit **29008** of the surgical instrument **29000** of FIG. **22**. The flexible circuit **2900** is present in the handle **29002**, the shaft assembly **29004**/**29005** and the end effector **29006**, and includes processing devices **29018**, logic elements **29020**, conductive traces **29022** and conductive pads **29024**. Although only one processing device **29018** and one logic element **29020** are shown in FIG. **23**, it will be appreciated that the flexible circuit **29008** may include any number of processing devices **29018** and/or logic elements **29020**. The conductive pads **29024** are configured for connection to other components of the surgical instrument **29000** such as sensing devices as described above, a motor (See conductive pads A and B in FIG. **24**) and slip rings (See conductive pads C and D in FIG. **24**). The conductive traces **29022** carry signals from sensors, to and from processing devices **29018**, to and from logic elements **29020**, to and from control circuits, to motors, etc. Although not shown for purposes of simplicity, the flexible circuit **29008** can also include a substrate, one or more insulation layers and an overlay. The processing devices **29018**, logic elements **29020**, etc. can be mounted on the substrate and the conductive traces **29022** and conductive pads **29024** can be patterned onto/over the substrate. The one or more insulation layers electrically insulate the conductive traces from one another. The overlay covers the insulation layer and/or the processing devices **29018**, logic elements **29020**, conductive traces **29022** and conductive pads **29024**. The flexible circuit **29008** can be one-sided as shown in FIG. **24**, or double-sided or multilayer. The conductive traces **29022** and conductive pads **29024** can include copper, gold, tin and/or other suitable conductive materials.

According to various aspects, in order to isolate the conductive traces **29022** from radiofrequency energy delivered by the surgical instrument **29000**, the flexible circuit **29008** includes electromagnetic shielding (e.g., guard traces or guard rings) that blocks radiofrequency electromagnetic radiation and/or minimizes signal cross-talk between the various conductive traces **29022**. The electromagnetic shielding does not have to be included throughout the flexible circuit **29008**. For example, according to various aspects, the electromagnetic shielding may only be positioned in select locations of the flexible circuit **29008** to protect the conductive traces **29022** from being subjected to unwanted effects or signals caused by external radiofrequency generators or magnets. For purposes of simplicity, the electromagnetic shielding is not shown in FIG. **24**.

The flexible circuit **29008** includes both rigid sections **29026** and flexible sections **29028**. Thus, the flexible circuit **29008** may also be referred to as a rigid-flex circuit. The rigid sections **29026** may be reinforced and are configured not to bend or flex to any significant degree. The rigid sections **29026** include portions of the conductive traces **29022**, and can also include, for example, one or more processing devices **29018**, one or more integrated circuits, one or more logic elements **29020** and/or conductive pads **29024** as shown in FIG. **24**. The actual positioning of devices such as non-chip gates and other logic elements **29020** allow for low level decision making local to the actuators of the surgical instrument **29000** (e.g., distributed processing).

According to various aspects, a first rigid section **29026** of the flexible circuit **29008** proximal to the articulation joint **29010** of the shaft assembly **29005** includes an interlock feature **29030** which is configured to snap into a recess **29032** defined by a first channel retainer **29034** (See FIG. **25**), and a second rigid section **29026** of the flexible circuit **29008** distal to the articulation joint **29010** of the shaft assembly **29005** includes an interlock feature which is configured to snap into a recess defined by a second channel retainer. Although the interlock feature of the second rigid section, the second channel retainer and its recess are not shown in FIG. **24** for purposes of simplicity, it will be appreciated that other than the positioning (proximal versus distal relative to the articulation joint), the interlock feature of the second rigid section may be similar or identical to the interlock feature **29030** of the first rigid section **29026**, the second channel retainer may be similar or identical to the first channel retainer **29034**, and the recess of the second channel retainer may be similar or identical to the recess **29032** of the first channel retainer **29034**. The first and second channel retainers **29034** are fixed within the surgical instrument **29000** and do not move relative to the surgical instrument **29000**. The snap-fit connection of the rigid sections **29026** to the channel retainers **29034** allows for the flexible circuit **29008** to be attached to the surgical instrument **29000** and prevents the flexible circuit **29008** from being "pulled-out" of position when the surgical instrument **29000** is required to be moved in various directions and/or the flexible circuit **29008** is subjected to various forces.

The flexible sections **29028** are configured to flex and bend as needed. For example, for a flexible section **29028** that is aligned with an active bending portion of the shaft assembly **20004** or with an articulating portion of the shaft assembly **29005** of the surgical instrument **29000**, the flexible section **29028** also needs to bendable in a similar manner to prevent unwanted stresses being applied to the flexible section **29028** and/or failure of the flexible section **29028**. Similarly, for instances where the flexible section **29028** needs to be stepped to cross over a mechanical component of the surgical instrument **29000** (e.g., an articulation rod of the surgical instrument), a flexible section **29028** of the flexible circuit **29008** allows for this to be realized (see, e.g., FIG. **23**). When the flexible circuit **29008** has forces, torsion or deformations applied to it, the flexible portions **29028** allow for the flexible circuit **29008** to flex more in one direction than in other directions, thereby preventing damage to the flexible circuit **29008** due to loading.

The flexible sections **29028** include portions of the conductive traces **29022**, can be stepped to cross over one or more mechanical components as described above, and/or can be folded in certain potentially high-stress areas (e.g., within an active bending portion of the shaft assembly **29004** as shown in FIG. **22** or within an articulation joint **29010** of the shaft assembly **29005**) in order to provide increased maneuverability, strength and/or resistance to failure.

According to various aspects, the respective cross-sections of the conductive traces **29022** can vary throughout the flexible circuit **29008**, even though the conductive traces **29022** still have the same or substantially similar current carrying capacity. The respective heights (h) or thicknesses of the conductive traces **29022** can be varied and/or the respective widths (w) of the conductive traces **29022** can be varied. For example, for a given conductive trace **29022** that is present in both a rigid section **29026** and a flexible section **29028**, the height (h) of the conductive trace **29022** may be

greater in the rigid section **29026** than in the flexible section **29028**, and the width (W) of conductive trace **29022** may be greater in the flexible section **29028** than in the rigid section **29026**. The combination of a lower height and a greater width in the flexible section **29028** allows the conductive trace **29022** to be more tolerable of the high stresses introduced by motions such as articulation motions and/or jaw closure motions. The length L shown in FIG. **24** is representative of the length of the articulating portion of the shaft assembly **29005** relative to the conductive traces **29022** aligned with the articulation joint **29010**.

FIG. **26** illustrates a cross-section of the flexible circuit **29008** along the line A-A of FIG. **24**, in accordance with at least one aspect of the present disclosure. The portion of the flexible circuit **29008** along the line A-A is distal to the bending portion of the shaft assembly **29004**/the articulation joint **29010** of the shaft assembly **29005** and may be considered a rigid portion **29026**. As shown in FIGS. **24** and **26**, the flexible circuit **29008** is not separated along the line A-A and the respective conductive traces **29022** in this portion of the flexible circuit **29008** have a height $h_a$ and a width $W_a$.

FIG. **27** illustrates a cross-section of the flexible circuit **29008** along the line B-B of FIG. **24**, in accordance with at least one aspect of the present disclosure. The portion of the flexible circuit **29008** along the line B-B is proximal to the bending portion of the shaft assembly **29004**/the articulation joint **29010** of the shaft assembly **29005** and may be considered a flexible portion **29028**. As shown in FIGS. **24** and **27**, the flexible circuit **29008** defines a separation or opening **29036** along the line B-B and the respective conductive traces **29022** in this portion of the flexible circuit **29008** have a height $h_b$ and a width $W_b$.

By comparing FIGS. **26** and **27**, it is apparent that the height ($h_a$) of the portions of the respective conductive traces **29022** along the line A-A (the portions of the conductive traces **29022** in the rigid section **29026**) is greater than the height ($h_b$) of the portions of the respective conductive traces **29022** along the line B-B (the portions of the conductive traces **29022** in the flexible section **29028**). Similarly, it is also apparent that the width ($W_a$) of the portions of the respective conductive traces **29022** along the line A-A (the portions of the conductive traces **29022** in the rigid section **29026**) is less than the width ($W_b$) of the portions of the respective conductive traces **29022** along the line B-B (the portions of the conductive traces **29022** in the flexible section **29028**). Stated differently, as depicted in FIG. **26**, $h_a > h_b$ and $W_a < W_b$.

For aspects of the surgical instrument **29000**, which include the articulation joint **29010** in the shaft assembly **29005**, for the portion of the flexible circuit **29008**, which passes through the articulation joint **29010** (a flexible section **29028** of the flexible circuit **29008**), the portions of the respective conductive traces **29022** are shorter/thinner and wider than the portions of the corresponding conductive traces **29022** are in the rigid section **29026**, which is distal and adjacent to the flexible section **29028**. Whereas traditional wires in this region typically have to be augmented with strain relief, the conductive traces **29022** of the flexible circuit **29008** in this region are made shorter/thinner and wider to allow the conductive traces **29022** of this flexible section **29028** to have the same current carrying capacity of those in the rigid sections **29026** while improving their flexibility. In view of the above, it will be appreciated that, a flexible section **29028** of the flexible circuit **29008** may be aligned to a pivot axis of the articulation joint **29010** of the shaft assembly **29005**, thereby allowing the flexible circuit **29008** to be bent up to 90° (or more) relative to a longitudinal axis **29038** of the shaft assembly **29005** and/or of the surgical instrument **29000**. Similar functionality can be realized for a portion of the flexible circuit **29008**, which passes through a pivot joint of the end effector **29006** and/or through the first and/or second jaws **29012**, **29014** of the surgical instrument **29000**. Thus, it can be appreciated that the flexible circuit **29008** includes elements (e.g., conductive traces **29022**) that have variable cross-sections where they are aligned with joints (e.g., the articulation joint **29010** of the shaft assembly **29005** and/or the pivot joint of the end effector **29006**) of the surgical instrument **29000**.

As shown in FIG. **22**, for the portion of the flexible circuit **29008**, which passes through the bendable portion of the shaft assembly **29004** (or through the articulation joint **29010** of the shaft assembly **29005**), the flexible circuit **29008** may be folded on each side of the separation or opening **29040** similar to a manner of that shown in FIG. **22**. The folding on each side of the separation or opening **29040** and the flexibility of the conductive traces **29022** allows for the wider portions of the conductive traces **29022** of the flexible section **29028** to fit within the limited area available within the articulation joint **29010** of the shaft assembly **29005**.

According to various aspects, the flexible circuit **29008** can include a twist or strain relief section **29042** incorporated into the flexible circuit **29008**. As shown in FIG. **22**, according to various aspects, the twist or strain relief section **29042** can be positioned between a rigid section **29026**, which includes the interlock feature **29030** and a flexible section **29028** which passes through the articulation joint **29010** of the shaft assembly **29005**. The twist or strain relief section **29042** allows the flexible circuit **29008** to first be attached to the first channel retainer **29034** (along a first plane along a length of the shaft assembly **29005** proximal to the articulation joint **29010**), then twist approximately 90° relative to the first plane to allow articulation about an axis perpendicular to the first plane). The twist or strain relief section **29042** is configured to safely relieve strains imposed on the flexible circuit **29008**.

By incorporating both rigid sections **29026** and flexible sections **29028** into the flexible circuit **29008** of the surgical instrument **29000**, the flexible circuit **29008** can mirror movements of the active bending sections of the shaft assembly **29004** or the articulation joint **29010** of the shaft assembly **29005** of the surgical instrument **29000** while remaining properly positioned within the surgical instrument **29000**. Such a combination provides a flexible circuit **29008**, which is more resistant to failure than those typically associated with surgical instruments **29000**.

FIG. **28** illustrates an exploded view of a flexible electrode **29100** of the surgical instrument **29000** of FIG. **22**, in accordance with at least one aspect of the present disclosure. According to various aspects, the flexible electrode **29100** can be integrated into the flexible circuit **29008** of FIG. **22** or at least be electrically coupled to the flexible circuit **29008**. Although not shown for purposes of clarity, it will be appreciated that the flexible electrode **29100** can be coupled to an electrosurgical generator and can receive electrosurgical energy (alternating current at RF levels) supplied by the electrosurgical generator.

The flexible electrode **29100** can be positioned on the first or second jaw **29012**, **29014** of the end effector **29006** of the surgical instrument **29000** and includes a therapeutic electrode **29102** and a sensing electrode **29104**. The therapeutic

electrode **29102** and the sensing electrode **29104** can include copper, gold, tin, or any other suitable material for conducting electricity.

The therapeutic electrode **29102** can have a rectangular shape and is configured to deliver RF energy to tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. According to various aspects, the therapeutic electrode **29102** can have a thickness in the range of about 0.003 inches.

The sensing electrode **29104** is configured to help determine one or more parameters associated with tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. For example, the sensing electrode **29104** may be configured to help determine the impedance of the tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. By sensing an amplitude, a frequency, a phase shift, etc., of a current passing through the tissue, the sensing electrode **29104** can pass the sensed "value" along to a processing circuit of the surgical instrument **29000**, which can then determine the impedance of the tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. An example of such a sensing electrode is described in commonly owned U.S. Pat. No. 5,817,093, titled IMPEDANCE FEEDBACK MONITOR WITH QUERY ELECTRODE FOR ELECTROSURGICAL INSTRUMENT, issued Oct. 6, 1998, the entire contents of which are hereby incorporated by reference. The sensing electrode **29104** can be continually sensing, even when RF energy is being delivered to the tissue by the therapeutic electrode **29102** for welding the tissue. According to various aspects, the sensing electrode **29104** can have a thickness similar or identical to the thickness of the therapeutic electrode **29102** (e.g., in the range of about 0.003 inches).

According to various aspects, the sensing electrode **29104** may also be configured to help determine tissue shrinkage and/or temperature transition points in the tissue. For example, by sensing an amplitude, a frequency, a phase shift, etc., of a current passing through the tissue, the sensing electrode **29104** can pass the sensed "value" along to a processing circuit of the surgical instrument **29000**, which can then utilize the sensed "values" to determine the electrical continuity of the tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. The processing circuit can then utilize the determined electrical continuity of the tissue to help determine the tissue shrinkage. When utilized in connection with the therapeutic electrodes **29102**, the sensing electrodes **29104** can allow for the detection of approaching transition temperature points associated with the tissue welding as the sensing electrodes **29104** are at a higher pressure than the therapeutic electrodes **29102** are. By utilizing the sensing capability of the sensing electrodes **29104**, the sensed "values" can be passed along to the processing circuit of the surgical instrument **29000**, which can then utilize the sensed "values" to identify impedance events before temperature transition points/inflection points occur in the less compressed zones of the tissue.

The sensing electrode **29104** has a patterned shape, overlays the therapeutic electrode **29102** and can have the same overall length and width of the therapeutic electrode **29102**, but due to the patterned shape doesn't completely cover the therapeutic electrode **29102**. As shown in FIG. **28**, according to various aspects the sensing electrode **29104** can be patterned as a modified "E-shape" with multiple rectangular fingers **29106**. When the sensing electrode **29104** overlays the therapeutic electrode **29102**, the spaces **29108** between the multiple rectangular fingers **29106** of the modified E-shape of the sensing electrode **29104** are aligned with portions of the therapeutic electrode **29102** which remain uncovered. According to other aspects, the patterned shape of the sensing electrode **29104** can be a modified E-shape with multiple triangular fingers or other shaped fingers.

The flexible electrode **29100** also includes a first insulative layer **29110** positioned between the therapeutic electrode **29102** and the sensing electrode **29104**. The first insulative layer **29110** can be patterned in the same manner as the sensing electrode **29104** (e.g., a modified E-shape with multiple rectangular fingers **29112**), is aligned with the sensing electrode **29104**, and electrically isolates the sensing electrode **29104** from the therapeutic electrode **29102**. According to various aspects, the first insulative layer **29110** is congruent with the sensing electrode **29104**. According to various aspects, when the first insulative layer **29110** overlays the therapeutic electrode **29102**, the spaces **29114** between the multiple rectangular fingers **29112** of the modified E-shape of the first insulative layer **29110** are aligned with the spaces **29108** between the multiple rectangular fingers **29106** of the modified E-shape of the sensing electrode **29104**, which are aligned with portions of the therapeutic electrode **29102**, which remain uncovered. According to other aspects, the multiple rectangular fingers **29112** of the modified E-shape of the first insulative layer **29110** can be slightly wider than the multiple rectangular fingers **29106** of the modified E-shape of the sensing electrode **29104** (see FIGS. **29** and **30**) such that the spaces **29114** can be slightly narrower than the spaces **29108**. According to various aspects, the first insulative layer **29110** has a thickness in the range of about 0.001 inches to 0.0003 inches. The first insulative layer **29110** may include any suitable electrically non-conductive material and can be more flexible than either the therapeutic electric **29102** or the sensing electrode **29104**.

The flexible electrode **29100** also includes a second insulative layer **29116** positioned to cover the surface of the therapeutic electrode **29102** opposite the surface of the therapeutic electrode **29102**, which is partially covered by the first insulative layer **29110** and the sensing electrode **29104**. The second insulative layer **29116** can have a rectangular shape which has the same overall length and width as the therapeutic electrode **29102**. According to various aspects, the second insulative layer **29116** can have a thickness in the range of about 0.0001 inches to 0.003 inches. The second insulative layer **29116** may include any suitable electrically non-conductive material and can be more flexible than either the therapeutic electric **29102** or the sensing electrode **29104**.

Although only one flexible electrode **29100** is shown in FIG. **28** for purposes of clarity, it is understood that the surgical instrument **29000** can include at least two of the flexible electrodes **29100** (e.g., one on the left hand side of a knife slot of the end effector **29006** of the surgical instrument **29000** and one on the right hand side of the knife slot). Additionally, as the flexible electrode **29100** includes multiple components and multiple layers, it will be appreciated that the flexible electrode **29100** can be considered a flexible electrode assembly and/or a multi-layered flexible electrode.

FIGS. **29** and **30** illustrate top views of a flexible electrode assembly **29200**, in accordance with at least one aspect of the present disclosure. The flexible electrode assembly **29200** includes two of the flexible electrodes **29100** of FIG. **28**, with a first one of the flexible electrodes **29100***a* positioned on the left hand side of a knife slot **29202** of the end

effector **29006** of the surgical instrument **29000** and a second one of the flexible electrodes **29100***b* positioned on the right hand side of the knife slot **29202**. With respect to the top views shown in FIGS. **29** and **30**, the sensing electrodes **29104***a* and **29104***b* are positioned above and partially cover the therapeutic electrodes **29102***a* and **29102***b*.

The surfaces of the respective sensing electrodes **29104***a*, **29104***b*, which can be in direct contact with tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**, are shown as being darkened in FIG. **29**. The darkened surfaces in FIG. **29** can be considered sensing electrode patterns. As set forth above, the sensing electrodes **29104** can help to determine the impedance of tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. When utilized in connection with the therapeutic electrodes **29102**, the sensing electrodes **29104** can allow for the detection of approaching transition temperature points associated with the tissue welding as the sensing electrodes **29104** are at a higher pressure than the therapeutic electrodes **29102** are. By utilizing the measurement capability of the sensing electrodes **29104**, impedance events can be identified before the inflection points occur in the less compressed zones of the tissue. Additionally, the sensing electrodes **29014** can also allow for measurement of tissue shrinkage if electrical continuity is measured by them. By using the sensing electrodes **29104** to measure continuity rather than impedance, the measured parameter can be indicative of tissue shrinkage rather than water driven out of the tissue. Furthermore, the sensing electrodes **29104** can be utilized to measure both impedance and continuity of the tissue. According to various aspects, the sensing electrodes **29104** can be also used as a conductive gap spacer to control a minimum gap between the first and second jaws **29012**, **29014** of the surgical instrument **29000**.

The recessed, non-continuous portions of the surfaces of the respective therapeutic electrodes **29102***a*, **29102***b*, which can be in direct contact with tissue positioned between the jaws of the surgical instrument **29000**, are shown as being darkened in FIG. **30**. The darkened surfaces in FIG. **30** can be considered therapeutic electrode patterns. Due to the recessed, segmented, non-continuous nature of the surfaces of the therapeutic electrodes **29102***a*, **29102***b* which can be in direct contact with tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**, the therapeutic electrodes **29102** can mitigate any unwanted tissue sticking when the therapeutic electrodes **29102** are energized. According to various aspects, a given recessed, non-continuous portion of a therapeutic electrode **29102** between two adjacent rectangular shaped fingers **29106** of a sensing electrode **29104** can be in the range of about 0.005" to 0.0008" greater in the longitudinal direction than the "length" of one of the rectangular shaped fingers **29106**. Stated differently, the surface area of a given recessed, non-continuous portion of a therapeutic electrode **29102** between two adjacent rectangular shaped fingers **29106** of a sensing electrode **29104** can be greater than the surface area of one of the rectangular shaped fingers **29106** of the sensing electrode **29104**. According to various aspects, at least one of the recessed, segmented, non-continuous portions of the surfaces of the therapeutic electrodes **29102** can be positioned in an offset or opposed electrode arrangement and can be coupled to a current return path which in turn can be coupled to an electrosurgical generator.

In view of the above, it will be appreciated that the flexible electrode assembly **29200** is a multi-level flexible electrode, which can measure one or more parameters associated with the surgical instrument **29000** and/or tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000** and can also cauterize the tissue.

FIG. **31** illustrates an exploded view of a flexible electrode **29300** of the surgical instrument **29000** of FIG. **22**, in accordance with at least one other aspect of the present disclosure. The flexible electrode **29300** of FIG. **31** is similar to the flexible electrode **29100** of FIG. **28**, but is different in that the flexible electrode **29300** of FIG. **31** further includes a third insulative layer **29302** positioned to partially cover the surface of the sensing electrode **29104** opposite the surface of the sensing electrode **29104**, which is covered by the first insulative layer **29110**. The third insulative layer **29302** can have a rectangular shape that has the same overall length as the sensing electrode **29104**, the first insulative layer **29110**, and/or the therapeutic electrode **29102** but has a width which is less than the width of the sensing electrode **29104**, the first insulative layer **29110**, the therapeutic electrode **29102**, and/or the second insulative layer **29116**. For example, according to various aspects, the third insulative layer **29302** can have a width which covers all of the sensing electrode **29104** except for the rectangular shaped fingers **29106**. According to other aspects, the third insulative layer **29302** can have a width that does not cover the rectangular shaped fingers **29106** and only partially covers the remaining portion of the sensing electrode **29104**. According to various aspects, the third insulative layer **29302** can have a thickness in the range of about 0.0001 inches to 0.003 inches. The third insulative layer **29302** may include any suitable electrically non-conductive material and can be more flexible than either the therapeutic electric **29102** or the sensing electrode **29104**.

FIG. **32** illustrates an end view of a flexible electrode **29400** of the surgical instrument **29000** of FIG. **22**, in accordance with at least one other aspect of the present disclosure. The flexible electrode **29400** of FIG. **32** is similar to the flexible electrode of FIG. **31** but is different. For the flexible electrode **29400** of FIG. **32**, the first insulative layer **29110** extends past the left hand side and the right hand side of the sensing electrode **29104** (relative to FIG. **32**), the second insulative layer **29116** extends past the left hand side and the right hand side of the therapeutic electrode **29102**, and the third insulative layer **29302** extends past one of the sides of the sensing electrode **29104**. In addition, the flexible electrode **29400** of FIG. **32** also includes insulative material **29402**, which covers one of the sides of the therapeutic electrode **29102** and one of the sides of the sensing electrode **29102** and connects the first, second, and third insulative layers **29110**, **29116**, **29302** together. The insulative material **29402** may be similar or identical to the material of the first, second, and/or third insulative layers **29110**, **29116**, **29302** and can be more flexible than either the therapeutic electrode **29102** or the sensing electrode **29104**. Furthermore, the flexible electrode **29400** of FIG. **32** can be a laminar composite construction that allows for multiple portions of the sensing electrode **29104** and/or the therapeutic electrode **29102** to be in contact with tissue positioned between the jaws of the surgical instrument **29000**, including portions of the sensing electrode **29104** and/or therapeutic electrode **29102**, which are buried within the laminate structure.

FIG. **33** illustrates a top perspective view of a flexible electrode **29500** of the surgical instrument **29000** of FIG. **22**, in accordance with at least one other aspect of the present disclosure. As shown in FIG. **33**, the flexible electrode **29500** further includes additional insulative material **29504**, which covers the side of the sensing electrode **29104** oppo-

site the side that is covered by the insulative material **29402**. The additional insulative material **29504** may be similar or identical to the material of the insulative material **29402** as well as the material of the first, second, and/or third insulative layers **29110**, **29116**, **29302**. The additional insulative material **29504** can be more flexible than either the therapeutic electrode **29102** or the sensing electrode **29104**. As shown in FIG. **33**, a long thin portion **29506** of the therapeutic electrode **29104** is uncovered and can be in direct contact with tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000**. The limited surface area of the long thin uncovered portion **29506** of the therapeutic electrode **29104** can mitigate any unwanted tissue sticking. Similarly, the non-continuous portions of the therapeutic electrode **29102** that are not covered by the first insulative member **29110** and/or the sensing electrode **29104** can also be in direct contact with tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000** and can also mitigate any unwanted tissue sticking.

As set forth above, one or more of the flexible electrodes **29100**, **29200**, **29300**, **29400**, **29500** can form part of a flexible circuit **29008** of the surgical instrument **29000**. According to various aspects, a termination contact arrangement can enable the flexible circuit **29008** to be easily attached to or connected with other connections and/or circuits within the surgical instrument **29000**. The termination contact arrangement can provide strain relief to the flexible circuit **29008** and the strain relief can mitigate damage to the portion of the flexible circuit **29008** adjacent the connection. The termination contact arrangement can also maintain the connection in a water-tight manner. According to various aspects, the termination contact arrangement can be a zero insertion force (ZIF) connector that electrically connects the flexible circuit **29008** with other connections and/or circuits within the surgical instrument **29000**. Such a ZIF connector can include both a self-sealing connection against fluids and provide strain relief to the portion of the flexible circuit **29008** adjacent the ZIF connector.

By incorporating therapeutic electrodes **29102** and sensing electrodes **29104** into flexible electrodes, the flexible electrodes can apply RF energy to tissue positioned between the first and second jaws **29012**, **29014** of the surgical instrument **29000** while also measuring parameters associated with the tissue and/or the surgical instrument **29000**. With the above-described configuration, the sensing electrodes **29104** can continually sense the parameters, even when the therapeutic electrodes **29102** are applying RF energy to the tissue for welding. Additionally, due to the partial overlapping of the "contact surface" of the therapeutic electrodes **29102** by the sensing electrodes **29104** and/or the first insulative layer **29110**, the therapeutic electrodes **29102** have less surface area in contact with the tissue and thus are less likely to contribute to unwanted tissue sticking. Furthermore, due to the inherent flexibility of the flexible electrodes, the therapeutic electrodes **29102** are less likely to experience premature failure due to unwanted flexing or deformation than electrodes typically associated with surgical instruments.

FIGS. **21-24** depict a motor-driven surgical instrument **150010** for cutting and fastening that may or may not be reused. In the illustrated examples, the surgical instrument **150010** includes a housing **150012** that comprises a handle assembly **150014** that is configured to be grasped, manipulated, and actuated by the clinician. The housing **150012** is configured for operable attachment to an interchangeable shaft assembly **150200** that has an end effector **150300** operably coupled thereto that is configured to perform one or more surgical tasks or procedures. In accordance with the present disclosure, various forms of interchangeable shaft assemblies may be effectively employed in connection with robotically controlled surgical systems. The term "housing" may encompass a housing or similar portion of a robotic system that houses or otherwise operably supports at least one drive system configured to generate and apply at least one control motion that could be used to actuate interchangeable shaft assemblies. The term "frame" may refer to a portion of a handheld surgical instrument. The term "frame" also may represent a portion of a robotically controlled surgical instrument and/or a portion of the robotic system that may be used to operably control a surgical instrument. Interchangeable shaft assemblies may be employed with various robotic systems, instruments, components, and methods disclosed in U.S. Pat. No. 9,072,535, titled SURGICAL STAPLING INSTRUMENTS WITH ROTATABLE STAPLE DEPLOYMENT ARRANGEMENTS, which is herein incorporated by reference in its entirety.

FIG. **34** is a perspective view of a surgical instrument **150010** that has an interchangeable shaft assembly **150200** operably coupled thereto, in accordance with at least one aspect of the present disclosure. The housing **150012** includes an end effector **150300** that comprises a surgical cutting and fastening device configured to operably support a surgical staple cartridge **150304** therein. The housing **150012** may be configured for use in connection with interchangeable shaft assemblies that include end effectors that are adapted to support different sizes and types of staple cartridges, have different shaft lengths, sizes, and types. The housing **150012** may be employed with a variety of interchangeable shaft assemblies, including assemblies configured to apply other motions and forms of energy, such as RF energy, ultrasonic energy, and/or motion to end effector arrangements adapted for use in connection with various surgical applications and procedures. The end effectors, shaft assemblies, handles, surgical instruments, and/or surgical instrument systems can utilize any suitable fastener, or fasteners, to fasten tissue. For instance, a fastener cartridge comprising a plurality of fasteners removably stored therein can be removably inserted into and/or attached to the end effector of a shaft assembly.

The handle assembly **150014** may comprise a pair of interconnectable handle housing segments **150016**, **150018** interconnected by screws, snap features, adhesive, etc. The handle housing segments **150016**, **150018** cooperate to form a pistol grip portion **150019** that can be gripped and manipulated by the clinician. The handle assembly **150014** operably supports a plurality of drive systems configured to generate and apply control motions to corresponding portions of the interchangeable shaft assembly that is operably attached thereto. A display may be provided below a cover **150045**.

FIG. **35** is an exploded assembly view of a portion of the surgical instrument **150010** of FIG. **34**, in accordance with at least one aspect of the present disclosure. The handle assembly **150014** may include a frame **150020** that operably supports a plurality of drive systems. The frame **150020** can operably support a "first" or closure drive system **150030**, which can apply closing and opening motions to the interchangeable shaft assembly **150200**. The closure drive system **150030** may include an actuator, such as a closure trigger **150032** pivotally supported by the frame **150020**. The closure trigger **150032** is pivotally coupled to the handle assembly **150014** by a pivot pin **150033** to enable the closure

trigger **150032** to be manipulated by a clinician. When the clinician grips the pistol grip portion **150019** of the handle assembly **150014**, the closure trigger **150032** can pivot from a starting or "unactuated" position to an "actuated" position and more particularly to a fully compressed or fully actuated position.

The handle assembly **150014** and the frame **150020** may operably support a firing drive system **150080** configured to apply firing motions to corresponding portions of the interchangeable shaft assembly attached thereto. The firing drive system **150080** may employ an electric motor **150082** located in the pistol grip portion **150019** of the handle assembly **150014**. The electric motor **150082** may be a DC brushed motor having a maximum rotational speed of approximately 25,000 RPM, for example. In other arrangements, the motor may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The electric motor **150082** may be powered by a power source **150090** that may comprise a removable power pack **150092**. The removable power pack **150092** may comprise a proximal housing portion **150094** configured to attach to a distal housing portion **150096**. The proximal housing portion **150094** and the distal housing portion **150096** are configured to operably support a plurality of batteries **150098** therein. Batteries **150098** may each comprise, for example, an LI or other suitable battery. The distal housing portion **150096** is configured for removable operable attachment to a control circuit board **150100**, which is operably coupled to the electric motor **150082**. Several batteries **150098** connected in series may power the surgical instrument **150010**. The power source **150090** may be replaceable and/or rechargeable. A display **150043**, which is located below the cover **150045**, is electrically coupled to the control circuit board **150100**. The cover **150045** may be removed to expose the display **150043**.

The electric motor **150082** can include a rotatable shaft (not shown) that operably interfaces with a gear reducer assembly **150084** mounted in meshing engagement with a set, or rack, of drive teeth **150122** on a longitudinally movable drive member **150120**. The longitudinally movable drive member **150120** has a rack of drive teeth **150122** formed thereon for meshing engagement with a corresponding drive gear **150086** of the gear reducer assembly **150084**.

In use, a voltage polarity provided by the power source **150090** can operate the electric motor **150082** in a clockwise direction wherein the voltage polarity applied to the electric motor by the battery can be reversed in order to operate the electric motor **150082** in a counter-clockwise direction. When the electric motor **150082** is rotated in one direction, the longitudinally movable drive member **150120** will be axially driven in the distal direction "DD." When the electric motor **150082** is driven in the opposite rotary direction, the longitudinally movable drive member **150120** will be axially driven in a proximal direction "PD." The handle assembly **150014** can include a switch that can be configured to reverse the polarity applied to the electric motor **150082** by the power source **150090**. The handle assembly **150014** may include a sensor configured to detect the position of the longitudinally movable drive member **150120** and/or the direction in which the longitudinally movable drive member **150120** is being moved.

Actuation of the electric motor **150082** can be controlled by a firing trigger **150130** that is pivotally supported on the handle assembly **150014**. The firing trigger **150130** may be pivoted between an unactuated position and an actuated position.

Turning back to FIG. **34**, the interchangeable shaft assembly **150200** includes an end effector **150300** comprising an elongated channel **150302** configured to operably support a surgical staple cartridge **150304** therein. The end effector **150300** may include an anvil **150306** that is pivotally supported relative to the elongated channel **150302**. The interchangeable shaft assembly **150200** may include an articulation joint **150270**. Construction and operation of the end effector **150300** and the articulation joint **150270** are set forth in U.S. Patent Application Publication No. 2014/0263541, titled ARTICULATABLE SURGICAL INSTRUMENT COMPRISING AN ARTICULATION LOCK, which is herein incorporated by reference in its entirety. The interchangeable shaft assembly **150200** may include a proximal housing or nozzle **150201** comprised of nozzle portions **150202**, **150203**. The interchangeable shaft assembly **150200** may include a closure tube **150260** extending along a shaft axis SA that can be utilized to close and/or open the anvil **150306** of the end effector **150300**.

Also on FIG. **34**, the closure tube **150260** is translated distally (direction "DD") to close the anvil **150306**, for example, in response to the actuation of the closure trigger **150032** in the manner described in the aforementioned reference U.S. Patent Application Publication No. 2014/0263541. The anvil **150306** is opened by proximally translating the closure tube **150260**. In the anvil-open position, the closure tube **150260** is moved to its proximal position.

FIG. **36** is another exploded assembly view of portions of the interchangeable shaft assembly **150200**, in accordance with at least one aspect of the present disclosure. The interchangeable shaft assembly **150200** may include a firing member **150220** supported for axial travel within the spine **150210**. The firing member **150220** includes an intermediate firing shaft **150222** configured to attach to a distal cutting portion or knife bar **150280**. The firing member **150220** may be referred to as a "second shaft" or a "second shaft assembly." The intermediate firing shaft **150222** may include a longitudinal slot **150223** in a distal end configured to receive a tab **150284** on the proximal end **150282** of the knife bar **150280**. The longitudinal slot **150223** and the proximal end **150282** may be configured to permit relative movement therebetween and can comprise a slip joint **150286**. The slip joint **150286** can permit the intermediate firing shaft **150222** of the firing member **150220** to articulate the end effector **150300** about the articulation joint **150270** without moving, or at least substantially moving, the knife bar **150280**. Once the end effector **150300** has been suitably oriented, the intermediate firing shaft **150222** can be advanced distally until a proximal sidewall of the longitudinal slot **150223** contacts the tab **150284** to advance the knife bar **150280** and fire the staple cartridge positioned within the channel **150302**. The spine **150210** has an elongated opening or window **150213** therein to facilitate assembly and insertion of the intermediate firing shaft **150222** into the spine **150210**. Once the intermediate firing shaft **150222** has been inserted therein, a top frame segment **150215** may be engaged with the shaft frame **150212** to enclose the intermediate firing shaft **150222** and knife bar **150280** therein. Operation of the firing member **150220** may be found in U.S. Patent Application Publication No. 2014/0263541. A spine **150210** can be configured to slidably support a firing member **150220** and the closure tube **150260** that extends around the spine **150210**. The spine **150210** may slidably support an articulation driver **150230**.

The interchangeable shaft assembly **150200** can include a clutch assembly **150400** configured to selectively and releasably couple the articulation driver **150230** to the firing

member **150220**. The clutch assembly **150400** includes a lock collar, or lock sleeve **150402**, positioned around the firing member **150220** wherein the lock sleeve **150402** can be rotated between an engaged position in which the lock sleeve **150402** couples the articulation driver **150230** to the firing member **150220** and a disengaged position in which the articulation driver **150230** is not operably coupled to the firing member **150220**. When the lock sleeve **150402** is in the engaged position, distal movement of the firing member **150220** can move the articulation driver **150230** distally and, correspondingly, proximal movement of the firing member **150220** can move the articulation driver **150230** proximally. When the lock sleeve **150402** is in the disengaged position, movement of the firing member **150220** is not transmitted to the articulation driver **150230** and, as a result, the firing member **150220** can move independently of the articulation driver **150230**. The nozzle **150201** may be employed to operably engage and disengage the articulation drive system with the firing drive system in the various manners described in U.S. Patent Application Publication No. 2014/0263541.

The interchangeable shaft assembly **150200** can comprise a slip ring assembly **150600**, which can be configured to conduct electrical power to and/or from the end effector **150300** and/or communicate signals to and/or from the end effector **150300**, for example. The slip ring assembly **150600** can comprise a proximal connector flange **150604** and a distal connector flange **150601** positioned within a slot defined in the nozzle portions **150202**, **150203**. The proximal connector flange **150604** can comprise a first face, and the distal connector flange **150601** can comprise a second face positioned adjacent to and movable relative to the first face. The distal connector flange **150601** can rotate relative to the proximal connector flange **150604** about the shaft axis SA-SA (FIG. **34**). The proximal connector flange **150604** can comprise a plurality of concentric, or at least substantially concentric, conductors **150602** defined in the first face thereof. A connector **150607** can be mounted on the proximal side of the distal connector flange **150601** and may have a plurality of contacts wherein each contact corresponds to and is in electrical contact with one of the conductors **150602**. Such an arrangement permits relative rotation between the proximal connector flange **150604** and the distal connector flange **150601** while maintaining electrical contact therebetween. The proximal connector flange **150604** can include an electrical connector **150606** that can place the conductors **150602** in signal communication with a shaft circuit board, for example. In at least one instance, a wiring harness comprising a plurality of conductors can extend between the electrical connector **150606** and the shaft circuit board. The electrical connector **150606** may extend proximally through a connector opening defined in the chassis mounting flange. U.S. Patent Application Publication No. 2014/0263551, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, is incorporated herein by reference in its entirety. U.S. Patent Application Publication No. 2014/0263552, titled STAPLE CARTRIDGE TISSUE THICKNESS SENSOR SYSTEM, is incorporated by reference in its entirety. Further details regarding slip ring assembly **150600** may be found in U.S. Patent Application Publication No. 2014/0263541.

The interchangeable shaft assembly **150200** can include a proximal portion fixably mounted to the handle assembly **150014** and a distal portion that is rotatable about a longitudinal axis. The rotatable distal shaft portion can be rotated relative to the proximal portion about the slip ring assembly **150600**. The distal connector flange **150601** of the slip ring assembly **150600** can be positioned within the rotatable distal shaft portion.

FIG. **37** is an exploded view of one aspect of an end effector **150300** of the surgical instrument **150010** of FIG. **34**, in accordance with at least one aspect of the present disclosure. The end effector **150300** may include the anvil **150306** and the surgical staple cartridge **150304**. The anvil **150306** may be coupled to an elongated channel **150302**. Apertures **150199** can be defined in the elongated channel **150302** to receive pins **150152** extending from the anvil **150306** to allow the anvil **150306** to pivot from an open position to a closed position relative to the elongated channel **150302** and surgical staple cartridge **150304**. A firing bar **150172** is configured to longitudinally translate into the end effector **150300**. The firing bar **150172** may be constructed from one solid section or may include a laminate material comprising a stack of steel plates. The firing bar **150172** comprises an I-beam **150178** and a cutting edge **150182** at a distal end thereof. A distally projecting end of the firing bar **150172** can be attached to the I-beam **150178** to assist in spacing the anvil **150306** from a surgical staple cartridge **150304** positioned in the elongated channel **150302** when the anvil **150306** is in a closed position. The I-beam **150178** may include a sharpened cutting edge **150182** to sever tissue as the I-beam **150178** is advanced distally by the firing bar **150172**. In operation, the I-beam **150178** may fire the surgical staple cartridge **150304**. The surgical staple cartridge **150304** can include a molded cartridge body **150194** that holds a plurality of staples **150191** resting upon staple drivers **150192** within respective upwardly open staple cavities **150195**. A wedge sled **150190** is driven distally by the I-beam **150178**, sliding upon a cartridge tray **150196** of the surgical staple cartridge **150304**. The wedge sled **150190** upwardly cams the staple drivers **150192** to force out the staples **150191** into deforming contact with the anvil **150306** while the cutting edge **150182** of the I-beam **150178** severs clamped tissue.

The I-beam **150178** can include upper pins **150180** that engage the anvil **150306** during firing. The I-beam **150178** may include middle pins **150184** and a bottom foot **150186** to engage portions of the cartridge body **150194**, cartridge tray **150196**, and elongated channel **150302**. When a surgical staple cartridge **150304** is positioned within the elongated channel **150302**, a slot **150193** defined in the cartridge body **150194** can be aligned with a longitudinal slot **150197** defined in the cartridge tray **150196** and a slot **150189** defined in the elongated channel **150302**. In use, the I-beam **150178** can slide through the aligned longitudinal slots **150193**, **150197**, and **150189** wherein, as indicated in FIG. **24**, the bottom foot **150186** of the I-beam **150178** can engage a groove running along the bottom surface of elongated channel **150302** along the length of slot **150189**, the middle pins **150184** can engage the top surfaces of cartridge tray **150196** along the length of longitudinal slot **150197**, and the upper pins **150180** can engage the anvil **150306**. The I-beam **150178** can space, or limit the relative movement between, the anvil **150306** and the surgical staple cartridge **150304** as the firing bar **150172** is advanced distally to fire the staples from the surgical staple cartridge **150304** and/or incise the tissue captured between the anvil **150306** and the surgical staple cartridge **150304**. The firing bar **150172** and the I-beam **150178** can be retracted proximally, allowing the anvil **150306** to be opened to release the two stapled and severed tissue portions.

FIGS. **38**A and **38**B are a block diagram of a control circuit **150700** of the surgical instrument **150010** of FIG. **34**

spanning two drawing sheets, in accordance with at least one aspect of the present disclosure. Referring primarily to FIGS. **38**A and **38**B, a handle assembly **150702** may include a motor **150714**, which can be controlled by a motor driver **150715** and can be employed by the firing system of the surgical instrument **150010**. In various forms, the motor **150714** may be a DC brushed driving motor having a maximum rotational speed of approximately 25,000 RPM. In other arrangements, the motor **150714** may include a brushless motor, a cordless motor, a synchronous motor, a stepper motor, or any other suitable electric motor. The motor driver **150715** may comprise an H-Bridge driver comprising FETs **150719**, for example. The motor **150714** can be powered by the power assembly **150706** releasably mounted to the handle assembly **150200** for supplying control power to the surgical instrument **150010**. The power assembly **150706** may comprise a battery that may include a number of battery cells connected in series that can be used as the power source to power the surgical instrument **150010**. In certain circumstances, the battery cells of the power assembly **150706** may be replaceable and/or rechargeable. In at least one example, the battery cells can be LI batteries, which can be separably couplable to the power assembly **150706**.

The shaft assembly **150704** may include a shaft assembly controller **150722**, which can communicate with a safety controller and power management controller **150716** through an interface while the shaft assembly **150704** and the power assembly **150706** are coupled to the handle assembly **150702**. For example, the interface may comprise a first interface portion **150725**, which may include one or more electric connectors for coupling engagement with corresponding shaft assembly electric connectors, and a second interface portion **150727**, which may include one or more electric connectors for coupling engagement with corresponding power assembly electric connectors to permit electrical communication between the shaft assembly controller **150722** and the power management controller **150716** while the shaft assembly **150704** and the power assembly **150706** are coupled to the handle assembly **150702**. One or more communication signals can be transmitted through the interface to communicate one or more of the power requirements of the attached interchangeable shaft assembly **150704** to the power management controller **150716**. In response, the power management controller may modulate the power output of the battery of the power assembly **150706**, as described below in greater detail, in accordance with the power requirements of the attached shaft assembly **150704**. The connectors may comprise switches that can be activated after mechanical coupling engagement of the handle assembly **150702** to the shaft assembly **150704** and/or to the power assembly **150706** to allow electrical communication between the shaft assembly controller **150722** and the power management controller **150716**.

The interface can facilitate transmission of the one or more communication signals between the power management controller **150716** and the shaft assembly controller **150722** by routing such communication signals through a main controller **150717** residing in the handle assembly **150702**, for example. In other circumstances, the interface can facilitate a direct line of communication between the power management controller **150716** and the shaft assembly controller **150722** through the handle assembly **150702** while the shaft assembly **150704** and the power assembly **150706** are coupled to the handle assembly **150702**.

The main controller **150717** may be any single core or multicore processor, such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the main controller **150717** may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other non-volatile memory, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, internal ROM loaded with StellarisWare® software, 2 KB EEPROM, one or more PWM modules, one or more QEI analog, or one or more 12-bit ADCs with 12 analog input channels, details of which are available for the product datasheet.

The safety controller may be a safety controller platform comprising two controller-based families, such as TMS570 and RM4x, known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

The power assembly **150706** may include a power management circuit that may comprise the power management controller **150716**, a power modulator **150738**, and a current sensor circuit **150736**. The power management circuit can be configured to modulate power output of the battery based on the power requirements of the shaft assembly **150704** while the shaft assembly **150704** and the power assembly **150706** are coupled to the handle assembly **150702**. The power management controller **150716** can be programmed to control the power modulator **150738** of the power output of the power assembly **150706** and the current sensor circuit **150736** can be employed to monitor power output of the power assembly **150706** to provide feedback to the power management controller **150716** about the power output of the battery so that the power management controller **150716** may adjust the power output of the power assembly **150706** to maintain a desired output. The power management controller **150716** and/or the shaft assembly controller **150722** each may comprise one or more processors and/or memory units that may store a number of software modules.

The surgical instrument **150010** (FIGS. **34-37**) may comprise an output device **150742**, which may include devices for providing a sensory feedback to a user. Such devices may comprise, for example, visual feedback devices (e.g., a liquid-crystal display (LCD) screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer), or tactile feedback devices (e.g., haptic actuators). In certain circumstances, the output device **150742** may comprise a display **150743**, which may be included in the handle assembly **150702**. The shaft assembly controller **150722** and/or the power management controller **150716** can provide feedback to a user of the surgical instrument **150010** through the output device **150742**. The interface can be configured to connect the shaft assembly controller **150722** and/or the power management controller **150716** to the output device **150742**. The output device **150742** can instead be integrated with the power assembly **150706**. In such circumstances, communication between the output device **150742** and the shaft assembly controller **150722** may be accomplished through the interface while the shaft assembly **150704** is coupled to the handle assembly **150702**.

The control circuit **150700** comprises circuit segments configured to control operations of the powered surgical instrument **150010**. A safety controller segment (Segment **1**) comprises a safety controller and the main controller **150717** segment (Segment **2**). The safety controller and/or the main controller **150717** are configured to interact with one or more additional circuit segments, such as an acceleration

segment, a display segment, a shaft segment, an encoder segment, a motor segment, and a power segment. Each of the circuit segments may be coupled to the safety controller and/or the main controller **150717**. The main controller **150717** is also coupled to a flash memory. The main controller **150717** also comprises a serial communication interface. The main controller **150717** comprises a plurality of inputs coupled to, for example, one or more circuit segments, a battery, and/or a plurality of switches. The segmented circuit may be implemented by any suitable circuit, such as, for example, a printed circuit board assembly (PCBA) within the powered surgical instrument **150010**. It should be understood that the term processor as used herein includes any microprocessor, processors, controller, controllers, or other basic computing device that incorporates the functions of a computer's CPU on an integrated circuit or, at most, a few integrated circuits. The main controller **150717** is a multipurpose, programmable device that accepts digital data as input, processes it according to instructions stored in its memory, and provides results as output. It is an example of sequential digital logic, as it has internal memory. The control circuit **150700** can be configured to implement one or more of the processes described herein.

The acceleration segment (Segment **3**) comprises an accelerometer. The accelerometer is configured to detect movement or acceleration of the powered surgical instrument **150010**. Input from the accelerometer may be used to transition to and from a sleep mode, identify an orientation of the powered surgical instrument, and/or identify when the surgical instrument has been dropped. In some examples, the acceleration segment is coupled to the safety controller and/or the main controller **150717**.

The display segment (Segment **4**) comprises a display connector coupled to the main controller **150717**. The display connector couples the main controller **150717** to a display through one or more integrated circuit drivers of the display. The integrated circuit drivers of the display may be integrated with the display and/or may be located separately from the display. The display may comprise any suitable display, such as, for example, an organic light-emitting diode (OLED) display, an LCD, and/or any other suitable display. In some examples, the display segment is coupled to the safety controller.

The shaft segment (Segment **5**) comprises controls for an interchangeable shaft assembly **150200** (FIGS. **34** and **36**) coupled to the surgical instrument **150010** (FIGS. **34-37**) and/or one or more controls for an end effector **150300** coupled to the interchangeable shaft assembly **150200**. The shaft segment comprises a shaft connector configured to couple the main controller **150717** to a shaft PCBA. The shaft PCBA comprises a low-power microcontroller with a ferroelectric random access memory (FRAM), an articulation switch, a shaft release Hall-effect switch, and a shaft PCBA EEPROM. The shaft PCBA EEPROM comprises one or more parameters, routines, and/or programs specific to the interchangeable shaft assembly **150200** and/or the shaft PCBA. The shaft PCBA may be coupled to the interchangeable shaft assembly **150200** and/or integral with the surgical instrument **150010**. In some examples, the shaft segment comprises a second shaft EEPROM. The second shaft EEPROM comprises a plurality of algorithms, routines, parameters, and/or other data corresponding to one or more shaft assemblies **150200** and/or end effectors **150300** that may be interfaced with the powered surgical instrument **150010**.

The position encoder segment (Segment **6**) comprises one or more magnetic angle rotary position encoders. The one or more magnetic angle rotary position encoders are configured to identify the rotational position of the motor **150714**, an interchangeable shaft assembly **150200** (FIGS. **34** and **36**), and/or an end effector **150300** of the surgical instrument **150010** (FIGS. **34-37**). In some examples, the magnetic angle rotary position encoders may be coupled to the safety controller and/or the main controller **150717**.

The motor circuit segment (Segment **7**) comprises a motor **150714** configured to control movements of the powered surgical instrument **150010** (FIGS. **34-37**). The motor **150714** is coupled to the main microcontroller processor **150717** by an H-bridge driver comprising one or more H-bridge FETs and a motor controller. The H-bridge driver is also coupled to the safety controller. A motor current sensor is coupled in series with the motor to measure the current draw of the motor. The motor current sensor is in signal communication with the main controller **150717** and/or the safety controller. In some examples, the motor **150714** is coupled to a motor electromagnetic interference (EMI) filter.

The motor controller controls a first motor flag and a second motor flag to indicate the status and position of the motor **150714** to the main controller **150717**. The main controller **150717** provides a PWM high signal, a PWM low signal, a direction signal, a synchronize signal, and a motor reset signal to the motor controller through a buffer. The power segment is configured to provide a segment voltage to each of the circuit segments.

The power segment (Segment **8**) comprises a battery coupled to the safety controller, the main controller **150717**, and additional circuit segments. The battery is coupled to the segmented circuit by a battery connector and a current sensor. The current sensor is configured to measure the total current draw of the segmented circuit. In some examples, one or more voltage converters are configured to provide predetermined voltage values to one or more circuit segments. For example, in some examples, the segmented circuit may comprise 3.3V voltage converters and/or 5V voltage converters. A boost converter is configured to provide a boost voltage up to a predetermined amount, such as, for example, up to 13V. The boost converter is configured to provide additional voltage and/or current during power-intensive operations and prevent brownout or low-power conditions.

A plurality of switches are coupled to the safety controller and/or the main controller **150717**. The switches may be configured to control operations of the surgical instrument **150010** (FIGS. **34-37**), of the segmented circuit, and/or indicate a status of the surgical instrument **150010**. A bail-out door switch and Hall-effect switch for bailout are configured to indicate the status of a bail-out door. A plurality of articulation switches, such as, for example, a left-side articulation left switch, a left-side articulation right switch, a left-side articulation center switch, a right-side articulation left switch, a right-side articulation right switch, and a right-side articulation center switch are configured to control articulation of an interchangeable shaft assembly **150200** (FIGS. **34** and **36**) and/or the end effector **150300** (FIGS. **34-37**). A left-side reverse switch and a right-side reverse switch are coupled to the main controller **150717**. The left-side switches comprising the left-side articulation left switch, the left-side articulation right switch, the left-side articulation center switch, and the left-side reverse switch are coupled to the main controller **150717** by a left flex connector. The right-side switches comprising the right-side articulation left switch, the right-side articulation right switch, the right-side articulation center switch, and the

right-side reverse switch are coupled to the main controller **150717** by a right flex connector. A firing switch, a clamp release switch, and a shaft engaged switch are coupled to the main controller **150717**.

Any suitable mechanical, electromechanical, or solid state switches may be employed to implement the plurality of switches, in any combination. For example, the switches may be limit switches operated by the motion of components associated with the surgical instrument **150010** (FIGS. **34-37**) or the presence of an object. Such switches may be employed to control various functions associated with the surgical instrument **150010**. A limit switch is an electromechanical device that consists of an actuator mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection. Limit switches are used in a variety of applications and environments because of their ruggedness, ease of installation, and reliability of operation. They can determine the presence or absence, passing, positioning, and end of travel of an object. In other implementations, the switches may be solid state switches that operate under the influence of a magnetic field, such as Hall-effect devices, MR devices, GMR devices, and magnetometers, among others. In other implementations, the switches may be solid state switches that operate under the influence of light, such as optical sensors, IR sensors, and ultraviolet sensors, among others. Still, the switches may be solid state devices such as transistors (e.g., FET, Junction-FET, MOSFET, bipolar, and the like). Other switches may include wireless switches, ultrasonic switches, accelerometers, and inertial sensors, among others.

FIG. **39** is another block diagram of the control circuit **150700** of the surgical instrument of FIG. **34** illustrating interfaces between the handle assembly **150702** and the power assembly **150706** and between the handle assembly **150702** and the interchangeable shaft assembly **150704**, in accordance with at least one aspect of the present disclosure. The handle assembly **150702** may comprise a main controller **150717**, a shaft assembly connector **150726**, and a power assembly connector **150730**. The power assembly **150706** may include a power assembly connector **150732**, a power management circuit **150734** that may comprise the power management controller **150716**, a power modulator **150738**, and a current sensor circuit **150736**. The shaft assembly connectors **150730**, **150732** form an interface **150727**. The power management circuit **150734** can be configured to modulate power output of the battery **150707** based on the power requirements of the interchangeable shaft assembly **150704**, while the interchangeable shaft assembly **150704** and the power assembly **150706** are coupled to the handle assembly **150702**. The power management controller **150716** can be programmed to control the power modulator **150738** of the power output of the power assembly **150706**, and the current sensor circuit **150736** can be employed to monitor power output of the power assembly **150706** to provide feedback to the power management controller **150716** about the power output of the battery **150707** so that the power management controller **150716** may adjust the power output of the power assembly **150706** to maintain a desired output. The shaft assembly **150704** comprises a shaft processor **150720** coupled to a non-volatile memory **150721** and shaft assembly connector **150728** to electrically couple the shaft assembly **150704** to the handle assembly **150702**. The shaft assembly connectors **150726**, **150728** form interface **150725**. The main controller **150717**, the shaft processor **150720**, and/or the power management controller **150716** can be configured to implement one or more of the processes described herein.

The surgical instrument **150010** (FIGS. **34-37**) may comprise an output device **150742** to a sensory feedback to a user. Such devices may comprise visual feedback devices (e.g., an LCD display screen, LED indicators), audio feedback devices (e.g., a speaker, a buzzer), or tactile feedback devices (e.g., haptic actuators). In certain circumstances, the output device **150742** may comprise a display **150743** that may be included in the handle assembly **150702**. The shaft assembly controller **150722** and/or the power management controller **150716** can provide feedback to a user of the surgical instrument **150010** through the output device **150742**. The interface **150727** can be configured to connect the shaft assembly controller **150722** and/or the power management controller **150716** to the output device **150742**. The output device **150742** can be integrated with the power assembly **150706**. Communication between the output device **150742** and the shaft assembly controller **150722** may be accomplished through the interface **150725** while the interchangeable shaft assembly **150704** is coupled to the handle assembly **150702**.

Tissue Marking

In various surgical procedures, surgical instruments seal tissue by application of energy or deployment of staples into the tissue. The surgical instruments may also sever or cut the sealed tissue. In a surgical procedure, one or more surgical instruments can be applied to several discrete tissue portions of a tissue being treated if the tissue size is greater than a maximum tissue size that can be handled by a surgical instrument in a single application. If a leak occurs in one of the treated tissue portions, it can be difficult to identify a surgical instrument, or a component thereof such as a staple cartridge, that was involved. Without such identification, it becomes difficult to determine the cause of the leak.

Aspects of the present disclosure present a surgical instrument that includes an end effector configured to apply a tissue treatment to tissue. The end effector includes a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, and a tissue-treatment mechanism configured to apply a tissue treatment to tissue grasped between the first jaw and the second jaw. In addition, the surgical instrument includes a marking assembly configured to apply a distinct marking to the tissue unique to each tissue treatment application, wherein the distinct marking distinguishes the tissue treatment application from other tissue treatment applications performed by the surgical instrument or other surgical instruments.

In various aspects, the tissue treatment mechanism comprises a staple cartridge configured to apply a tissue treatment application by deploying staples into tissue grasped by an end effector. In other aspects, the tissue treatment mechanism comprises an energy device configured to apply a tissue treatment application by delivering therapeutic energy to tissue grasped by an end effector. The energy delivered by the energy device can be in the form of RF energy or ultrasonic energy, for example.

In various aspects, the tissue treatment mechanism comprises a transection member movable to apply tissue treatment application by transecting the grasped tissue. One or both of the jaws of the end effector may include longitudinal slots configured to accommodate the transection member. The transection member may include a cutting edge at a distal portion thereof.

FIG. **40** illustrates a logic flow diagram of a process **31010** depicting a control program or a logic configuration

for marking tissue treated by an end effector of a surgical instrument, in accordance with at least one aspect of the present disclosure. In one aspect, as described in greater detail below, the process **31010** is executed by a control circuit **500** (FIG. **13**). In another aspect, the process **31010** can be executed by a combinational logic circuit **510** (FIG. **14**). In yet another aspect, the process **31010** can be executed by a sequential logic circuit **520** (FIG. **15**).

In the example of FIGS. **41-44**, tissue is treated by an end effector **31000** of a surgical stapling and cutting instrument **31006** and is marked by a marking assembly **31020** of a control system **31470**.

The surgical instrument **31006** is similar in many respects to the surgical instrument **150010**. For example, the end effector **31000** and the control system **31470** are similar in many respects to the end effector **150300** and the control circuit **470** (FIG. **12**), respectively. Components of the surgical instrument **31006** that are similar to above-described components of the surgical instrument **150010** are not repeated herein in detail for conciseness.

The end effector **31000** includes a first jaw **31001** and a second jaw **31002** extending from an interchangeable shaft assembly **150200**. The end effector **31000** further includes an anvil defined in the first jaw **31001** and a staple cartridge **31005** defined in the second jaw **31002**. At least one of the first jaw **31001** and the second jaw **31002** is movable relative to the other to transition the end effector **26000** between an open configuration and a closed configuration to grasp tissue between the anvil and the staple cartridge **31005**. In operation, a tissue treatment by the surgical instrument **31006** involves deploying staples from the staple cartridge **26005** by a firing member into the grasped tissue. The deployed staples are deformed by the anvil. In various aspects, the tissue can also be treated by transection using a cutting member movable relative to a longitudinal slot **31007** defined in at least one of the first jaw **31001** and the second jaw **31002**.

In various aspects, a surgical instrument, in accordance with the present disclosure, may include an end effector that treats tissue by application of RF or ultrasonic energy to tissue. In various aspects, the surgical instrument **26010** can be a handheld surgical instrument. Alternatively, the surgical instrument **26010** can be incorporated into a robotic system as a component of a robotic arm. Additional details on robotic systems are disclosed in U.S. Provisional Patent Application No. 62/611,339, filed Dec. 28, 2017, which is incorporated herein by reference in its entirety.

Referring again to FIG. **40**, the process **31010** includes receiving **31011** sensor signals indicative of application of a tissue treatment. If it is determined **31012**, based on the received sensor signals, that a tissue treatment has been, or is being, applied to the tissue, a distinct marking is applied **31013** to the tissue. The distinct marking is unique to the tissue treatment application and can be utilized to distinguish the tissue treatment application from other tissue treatment applications.

Referring to FIG. **44**, in various aspects, the process **31010** can be performed by a control system **31470** of the surgical instrument **31006**. The control system **31470** is similar in many respects to the control system **470** (FIG. **12**). For example, the control system **31470** includes a control circuit that has a microcontroller **470**. A number of sensors **472**, **474**, **476**, **31473** provide various sensor signals to the microcontroller **470**. One or more of such sensor signals can be analyzed alone, or in combination with other sensor signals, to determine whether a tissue treatment has been, or is being, applied to tissue. The control system **31470** further includes a marking assembly **31020** in communication with the microcontroller **470**. After determining that a tissue treatment has been, or is being, applied to tissue, the microcontroller **470** causes the marking assembly **31020** to mark the tissue.

In various instances, the marking of the tissue by the marking assembly **31020** can be triggered by input from an operator of the surgical instrument **31006**, which can be delivered through a user interface such as, for example, the display **473**. Alternatively, or in addition, the marking of the tissue can be triggered by one or more sensor signals.

In one example, readings from the strain gauge sensor **474**, which can be used to measure the force applied to tissue grasped by the end effector **31000**, can trigger the tissue marking. The microcontroller **461**, upon receipt of a sensor signal from the sensor **474** beyond a predetermined threshold, which indicates that tissue is grasped by the end effector **31000**, may cause the marking assembly **31020** to mark the tissue.

In one example, readings from an activation sensor **31473**, which can be used to detect deployment of staples or energy application to tissue, can trigger the tissue marking. The microcontroller **461**, upon receipt of a sensor signal from the sensor **31473** beyond a predetermined threshold, may instruct the marking assembly **31020** to mark the tissue.

In the example of FIGS. **41** and **43**, the marking assembly **31020** includes two marking applicators **31021**, **31022** disposed on the second jaw **31002**. More specifically, the applicator **31021** is disposed on a proximal portion **31008** of a staple cartridge **31005** assembled with the second jaw **31002**, while the applicator **31022** is disposed on a distal portion **31009** of the staple cartridge **31005**. In other arrangements, more or less than two applicators can be disposed onto one or more jaws of an end effector to apply markings to tissue treated by the end effector.

Each of the applicators **31021**, **31022** includes markers **31023**, which are arranged in a predetermined pattern. As illustrated in FIG. **44**, the markers **31023** of the applicators **31021**, **31022** are arranged in three rows. Also, the applicators **31021**, **31022** comprise the same number and arrangement of markers **31023**. In certain instances, however, the markers of an applicator can be arranged in any suitable arrangement. Different applicators may comprise the same or different marker arrangements. In certain instances, all of the markers of an applicator are activated to generate a tissue marking. In other instances, only some of the markers of an applicator are activated to generate a tissue marking. The activation of the markers can be controlled by the microcontroller **461** to yield a predetermined marking.

In various instances, the markers **31023** can be configured to apply their individual marks at the same intensity. Alternatively, the markers **31023** can be configured to apply their individual marks at different intensities. The intensity of the marks can be controlled by the microcontroller **461** to yield a predetermined marking.

In various instances, as illustrated in FIG. **41**, the applicators **31021**, **31022** are arranged at proximal and distal portions **31008**, **31009**, respectively, of the second jaw **31002**. This arrangement allows the applicators **31021**, **31022** to apply their markings proximal and distal to a tissue treatment, which can assist in identifying the beginning and end of the tissue treatment.

In various instances, one or more of the markings are detectable through stimulation by at least one of a light source, a radiation source, and an illumination source. In certain instances, the markers **31023** are configured to apply one or more fluorescent materials to the tissue causing the

markings to be visible only in the presence of a light source outside of the visible spectrum. In other words, the markings will fluoresce under an applied light source outside of the visible spectrum.

In certain instances, the makers **31023** are configured to use an IR readable ink formulation in generating the markings. The ink formulation can be based on absorption and reflection of light in the IR. As illustrated in FIG. **45**, the markers **31023** can be configured to generate unique IR ink markings **31035**, **31037**.

In certain instances, the markers **31023** are in the form of electrodes that are selectively activatable by the microcontroller **461** to generate the markings. The microcontroller **461** may control the intensity of each mark by controlling the activation time of the electrodes. The longer an electrode is activated, the greater the intensity of the mark. Segmentation can be introduced within the electrodes to leave a distinctive marking. In certain instances, the markers **31023** can be equipped with RF electrodes, including a series of micro electrodes configured to weld an optically identifiable distinct marking for each application of a tissue treatment.

Referring to FIGS. **42** and **45**, eight tissue portions received eight treatments performed by an end effector **31030** of a surgical instrument **31036**. FIG. **43** depicts a jaw **31002** of the end effector **31030**. In each of the eight treatments, the end effector **31030** grasped a tissue portion, sealed the tissue portion, and cut the tissue portion. The treatments were applied in a particular order, as illustrated in FIG. **45**, to separate a cancerous portion of the colon from neighboring tissue T. A marking assembly **31033**, which includes applicators **31031**, **31032**, applied distinct tissue markings to each tissue portion with each treatment.

The surgical instrument **31036** is similar in many respects to the surgical instruments **31006**, **150010**. For example, the end effector **31000** is similar in many respects to the end effectors **31000**, **150300**. Components of the surgical instrument **31036** that are similar to above-described components of the surgical instruments **31006**, **150010** are not repeated herein in detail for conciseness.

In the example of FIG. **42**, the applicators **31031**, **31032** are disposed at a proximal portion **31009** of a second jaw **31034** on opposite sides **31038**, **31039** of a transection path defined by the longitudinal slot **31007** along a longitudinal axis LA. In this arrangement, each side of the transected tissue receives a distinct marking.

In various instances, as illustrated in FIG. **45**, the marking could be made in such an order that the sequence of the marks from one use to the next provides a distinct marking for a sequence of consecutive treatments. This would allow a unique marking over a series of treatments in addition to the markings associated with individual treatments. Said another way, the markings associated with related treatments may include a common identifier in addition to their unique identifiers. Treatments can be related by virtue of being fired consecutively in a surgical procedure or by a single surgical instrument.

In various aspects, the surgical instruments of the present disclosure such as, for example, the surgical instruments **26010**, **31006**, **310036** are communicatively coupled to a surgical hub (e.g., surgical hubs **106** (FIG. **2**, FIG. **3**), **206** (FIG. **10**)) through a wired and/or wireless communication channels. Data gathered by such surgical instruments can be transmitted to the surgical hub **106**, **206**, which may further transmit the data to a cloud-based system (e.g., cloud-based systems **104**, **204**), for additional analysis.

Further to the above, a visualization system (e.g., visualization systems **108** (FIG. **3**), **208** (FIG. **9**)), may record frames of the marked tissue for subsequent identification after a surgical instrument is moved from a surgical site. The data from the surgical instrument and the frames recorded by a visualization system and can be transmitted to a surgical hub, which may time stamp and/or correlate the data received from both sources. The data can also be forwarded to the cloud-based system for additional analysis.

This process can be helpful in analyzing failures. For example, as illustrated in FIG. **45**, a leak **31039** has occurred at the seventh tissue treatment. The distinct marking at the seventh tissue treatment, which is recorded by the visualization system, will help identify the surgical instrument that performed the seventh treatment. Accordingly, the operational data **31040** at the seventh treatment can be examined and compared to operational data **31042** of the same surgical instrument within the same environment that yielded successful application of similar treatments. As described above, the markings of a single surgical procedure or those created by a single surgical instrument may include a common identifier allowing for a quick comparison of the operational data **31040** and the operational data **31042**.

In the example of FIG. **45**, the operation data at the first tissue treatment application, which yielded a successful seal, is compared to the operational data at the seventh tissue treatment application, which yielded the leak. In comparing the two data sets, it becomes clear that the leak was caused by an unusual drop in clamp force, which can be addressed in subsequent tissue treatments with the same or similar surgical instruments. In other instances, the operational data of the surgical instrument associated with a failure are compared to preset standards.

In certain instances, the above-described failure analysis can be performed by a surgical hub in real time during a surgical procedure. Leak detection and deciphering tissue marking can be performed by various image processing techniques. The surgical operator can be guided back to the surgical site with the aid of the surgical hub by identify anatomical landmarks and the inherent variable shading of the tissues using a dot-by-dot analysis technique. In certain instances, landmarks can be identified and acquired by observing hot spots in tissue after energy application.

Data Transmission Prioritization

Various data can be gathered and/or generated by a powered surgical instrument during a surgical procedure. For example, a powered surgical stapling and cutting instrument may collect, among other things, force-to-clamp (FTC) and force-to-fire (FTF) readings, which can be transmitted to a surgical hub that further transmits the data to a cloud-based system for additional processing. A communication pathway between the powered surgical instrument and the surgical hub has a predetermined bandwidth. Likewise, a communication pathway between the surgical hub and the cloud-based system also has a predetermined bandwidth. In certain instances, various environmental interferences may further limit such bandwidths. Moreover, various data sources may compete for the limited bandwidths.

During a surgical procedure, a surgical hub may react to the received data by adjusting various parameters at its control in real time. Depending on the surgical step being performed, certain data sources and/or surgical activities become more important than others. Transmitting the data without considering its importance may interfere with operation of the surgical hub and its ability to make timely decisions. Likewise, a delay in data transmission due to bandwidth limits may interfere with operation of the surgical hub and its ability to make timely decisions.

In various aspects, a surgical system **32002** is used in a surgical procedure. The surgical system **32002** includes a surgical hub (e.g., surgical hub **106** (FIG. **3**, FIG. **4**, FIG. **49**), surgical hub **206** (FIG. **10**)), a powered surgical instrument (e.g., Device/Instrument **235** (FIG. **9**), surgical instrument **32235** (FIG. **49**)), and a communication module **32004** (FIG. **49**). The communication module **32004** includes a shift/register **32005** and a transceiver **32007**.

FIG. **48** illustrates a logic flow diagram of a process **32000** depicting a control program or a logic configuration for coordinating transmission of data between the powered surgical instrument **32235** and a surgical hub (e.g., surgical hub **106** (FIG. **3**, FIG. **4**, FIG. **49**), surgical hub **206** (FIG. **10**)), in accordance with at least one aspect of the present disclosure. The process **32000** includes receiving **32006** first data regarding a first surgical activity of the surgical procedure, receiving **32008** second data regarding a second surgical activity of the surgical procedure, selecting **32010** transmission rates for transmission the first data and the second data between the powered surgical instrument **32235** and the surgical hub **106** based on at least one characteristic of at least one of the first surgical activity and the second surgical activity, and transmitting **32012** the first data and the second data between the powered surgical instrument and the surgical hub at the selected transmission rates.

In at least one example, the process **32000** selects or adjusts transmission rates for transmission of the first data and the second data between the powered surgical instrument **32235** and the surgical hub **106** based on at least one characteristic of at least one of the first surgical activity and the second surgical activity and available bandwidth. The communication module **32004** may determine available bandwidth, which may change over time based on various factors such as, for example, interference and other environmental factors.

FIG. **49** illustrates a control system **32470** of the surgical instrument **32235**, which can be employed to execute the process of FIG. **48**. The control system **32470** is similar in many respects to the control system **470** (FIG. **12**). In various aspects, the process **32000** can be executed by the communication module **32004** of the surgical instrument **32235**, which includes a microcontroller **461** coupled to sensors **472**, **474**, **476**, as illustrated in FIG. **49**.

In various aspects, the first data can be received from a first source and the second data received from a second source different than the first source. The first source and/or the second source may be any of the sensors **472**, **474**, **476**, for example.

In various aspects, the surgical instrument **32235** is similar in many respects to the surgical instruments **235** (FIG. **9**), **150010** (FIG. **35**). For example, like the surgical instrument **150010**, the surgical instrument **32235** includes an end effector **150300** transitionable, in a first surgical activity, from an open configuration, as illustrated in FIG. **25**, to a closed configuration to grasp tissue. A motor **482** (FIG. **49**) may drive the transition of the end effector **150300** between the open configuration and the closed configuration. In certain instances, the first data represent the force required to FTC the end effector **150300** over time, as illustrated in FIG. **46**.

In various aspects, the surgical instrument **32235** comprises a displacement member (e.g., drive member **150120** of FIG. **39**) movable, in the second surgical activity, to deploy/fire staples into the tissue grasped by the end effector **150300**. In certain instances, the second data represent FTF the end effector **150300** over time, as illustrated in FIG. **46**.

FIG. **46** is a graph illustrating FTC and FTF readings for the powered surgical instrument **32235** during a surgical procedure plotted against time (t). Corresponding transmission rates of the FTC and FTF readings to a surgical hub **106** are also plotted against time (t). In the example of FIGS. **46** and **47**, the sensors **472**, **474**, **476** comprise an ideal sampling rate of 30 samples per second. A sampling rate is a rate at which a reading is taken.

The communication channel between the powered surgical instrument **32235** and the surgical hub **106** comprises a first bandwidth capable of transmissions up to 25 Megabits per second, which corresponds to a maximum of 62 samples transmitted per second. The first bandwidth is reduced to a second bandwidth at a time $t=t_2$, due to environmental interferences within the operating room. The second bandwidth is capable of transmissions up to 20 Megabits per second, which corresponds to a maximum of 48 samples per second. FIG. **47** also lists actual FTC and FTF samples transmitted per second at four example time points ($t_1$, $t_2$, $t_3$, $t_4$) selected for illustration purposes.

Referring again to FIGS. **46** and **47**, the first surgical activity, represented by FTC data, begins at time t=0 while the second surgical activity, represented by FTF data, begins at time $t=t_3$. The first surgical activity also reaches a maximum FTC, which defines an important characteristic of the first surgical activity, at $t=t_1$. Accordingly, up to the time $t=t_3$, it is desirable to prioritize transmission of FTC data associated with the first surgical activity over FTF data associated with the second surgical activity. As illustrated at $t=t_1$, which corresponds to the maximum FTC values, FTC data is transmitted at an optimal transmission rate corresponding to 30 samples per second while no FTF data is transmitted during this initial stage.

Further to the above, a negative transition in bandwidth or maximum available transmission rate occurs at t=ta, and is sensed by the communication module **32004**. In response, the transmission rate of the FTC data is lowered to a transmission rate corresponding to 26 samples per second, as illustrated at $t=t_2$, in order to accommodate the negative transition caused by the environmental interferences. In various instances, the first data and the second data are transmitted through a communication channel established between the powered surgical instrument **32235** and the surgical hub **106**, and the communication module **32004** adjusts the transmission rate of at least one of the first data and the second data in response to the change in bandwidth of the communication channel.

In the example of FIGS. **47** and **48**, only the FTC data transmission rate is lowered, from 30 to 26 samples per seconds because the FTF data transmission rate is already at 0 samples per seconds. In other instances, an ongoing prioritization scheme, which is instituted based on a characteristic of at least one of the first surgical activity and the second surgical activity, may impact the effect of a negative transition in bandwidth on the transmission rates of the first data and/or the second data, as described in greater detail below.

At $t=t_3$, FTF data and FTC data become equally relevant. Due to the reduction in bandwidth or maximum available transmission rates, however, only 48 samples can be transmitted per second. Accordingly, the transmission rates of the FTC data and the FTF data are adjusted to be the same at 24 samples per second. In other words, the transmission rates of the FTC data and the FTF data are adjusted to accommodate the increased relevance of the FTF data and the negative transition in bandwidth or maximum available transmission rates.

Further to the above, as the FTF data ramps upward and the FTC data tails off, the FTF data can be prioritized over the FTC data. Accordingly, the transmission rate of the FTF data can be increased, and the transmission rate of the FTC data decreased for the remainder of the second surgical activity. In other words, the communication module **32004** may adjust transmission rates for transmission of the first data and the second data between the powered surgical instrument and the surgical hub based on a characteristic of at least one of the first surgical activity and the second surgical activity.

At $t=t_4$, an irregular FTF is detected as the FTF has exceeded a predetermined threshold. To investigate the irregular FTF, the communication module **32004** responds by increasing the FTF data transmission rate to 40 samples per second, while decreasing the FTC transmission rate to 8 samples per second. In other words, the communication module **32004** responds to the sensed irregularity in FTF data by adjusting the transmission rates to prioritize transmission of FTF data over FTC data.

FIG. **50** illustrates a logic flow diagram of a process **32100** depicting a control program or a logic configuration for coordinating transmission of data between the powered surgical instrument **32235** and a surgical hub (e.g., surgical hub **106** (FIG. **3**, FIG. **4**, FIG. **49**), surgical hub **206** (FIG. **10**)), in accordance with at least one aspect of the present disclosure. The process **32100** includes receiving **32106** first data regarding a first surgical activity of the surgical procedure, receiving **32108** second data regarding a second surgical activity of the surgical procedure, and transmitting **32112** the first data and the second data between the powered surgical instrument **32235** and the surgical hub **106**.

Further to the above, if an irregularity is detected **32109**, the process **32100** adjusts **32110** transmission rates for transmission the first data and the second data between the powered surgical instrument **32235** and the surgical hub **106** to prioritize transmission of the data encompassing the irregularity. As described above, an irregularity, in accordance with the process **32109** can be exceeding a predetermined threshold.

In various aspects, the communication module **32004** sets a preferred or prioritized communication processing arrangement to insure the flow of low-speed data and high-speed connections while still enabling prioritization of slow bandwidth data if its need is a higher priority.

Situational Awareness

Situational awareness is the ability of some aspects of a surgical system to determine or infer information related to a surgical procedure from data received from databases and/or instruments. The information can include the type of procedure being undertaken, the type of tissue being operated on, or the body cavity that is the subject of the procedure. With the contextual information related to the surgical procedure, the surgical system can, for example, improve the manner in which it controls the modular devices (e.g. a robotic arm and/or robotic surgical tool) that are connected to it and provide contextualized information or suggestions to the surgeon during the course of the surgical procedure.

Referring now to FIG. **51**, a timeline **5200** depicting situational awareness of a hub, such as the surgical hub **106** or **206**, for example, is depicted. The timeline **5200** is an illustrative surgical procedure and the contextual information that the surgical hub **106**, **206** can derive from the data received from the data sources at each step in the surgical procedure. The timeline **5200** depicts the typical steps that would be taken by the nurses, surgeons, and other medical personnel during the course of a lung segmentectomy procedure, beginning with setting up the operating theater and ending with transferring the patient to a post-operative recovery room.

The situationally aware surgical hub **106**, **206** receives data from the data sources throughout the course of the surgical procedure, including data generated each time medical personnel utilize a modular device that is paired with the surgical hub **106**, **206**. The surgical hub **106**, **206** can receive this data from the paired modular devices and other data sources and continually derive inferences (i.e., contextual information) about the ongoing procedure as new data is received, such as which step of the procedure is being performed at any given time. The situational awareness system of the surgical hub **106**, **206** is able to, for example, record data pertaining to the procedure for generating reports, verify the steps being taken by the medical personnel, provide data or prompts (e.g., via a display screen) that may be pertinent for the particular procedural step, adjust modular devices based on the context (e.g., activate monitors, adjust the field of view (FOV) of the medical imaging device, or change the energy level of an ultrasonic surgical instrument or RF electrosurgical instrument), and take any other such action described above.

As the first step S**202** in this illustrative procedure, the hospital staff members retrieve the patient's EMR from the hospital's EMR database. Based on select patient data in the EMR, the surgical hub **106**, **206** determines that the procedure to be performed is a thoracic procedure.

Second step S**204**, the staff members scan the incoming medical supplies for the procedure. The surgical hub **106**, **206** cross-references the scanned supplies with a list of supplies that are utilized in various types of procedures and confirms that the mix of supplies corresponds to a thoracic procedure. Further, the surgical hub **106**, **206** is also able to determine that the procedure is not a wedge procedure (because the incoming supplies either lack certain supplies that are necessary for a thoracic wedge procedure or do not otherwise correspond to a thoracic wedge procedure).

Third step S**206**, the medical personnel scan the patient band via a scanner that is communicably connected to the surgical hub **106**, **206**. The surgical hub **106**, **206** can then confirm the patient's identity based on the scanned data.

Fourth step S**208**, the medical staff turns on the auxiliary equipment. The auxiliary equipment being utilized can vary according to the type of surgical procedure and the techniques to be used by the surgeon, but in this illustrative case they include a smoke evacuator, insufflator, and medical imaging device. When activated, the auxiliary equipment that are modular devices can automatically pair with the surgical hub **106**, **206** that is located within a particular vicinity of the modular devices as part of their initialization process. The surgical hub **106**, **206** can then derive contextual information about the surgical procedure by detecting the types of modular devices that pair with it during this pre-operative or initialization phase. In this particular example, the surgical hub **106**, **206** determines that the surgical procedure is a VATS procedure based on this particular combination of paired modular devices. Based on the combination of the data from the patient's EMR, the list of medical supplies to be used in the procedure, and the type of modular devices that connect to the hub, the surgical hub **106**, **206** can generally infer the specific procedure that the surgical team will be performing. Once the surgical hub **106**, **206** knows what specific procedure is being performed, the surgical hub **106**, **206** can then retrieve the steps of that procedure from a memory or from the cloud and then

cross-reference the data it subsequently receives from the connected data sources (e.g., modular devices and patient monitoring devices) to infer what step of the surgical procedure the surgical team is performing.

Fifth step **S210**, the staff members attach the EKG electrodes and other patient monitoring devices to the patient. The EKG electrodes and other patient monitoring devices are able to pair with the surgical hub **106**, **206**. As the surgical hub **106**, **206** begins receiving data from the patient monitoring devices, the surgical hub **106**, **206** thus confirms that the patient is in the operating theater.

Sixth step **S212**, the medical personnel induce anesthesia in the patient. The surgical hub **106**, **206** can infer that the patient is under anesthesia based on data from the modular devices and/or patient monitoring devices, including EKG data, blood pressure data, ventilator data, or combinations thereof, for example. Upon completion of the sixth step **S212**, the pre-operative portion of the lung segmentectomy procedure is completed and the operative portion begins.

Seventh step **S214**, the patient's lung that is being operated on is collapsed (while ventilation is switched to the contralateral lung). The surgical hub **106**, **206** can infer from the ventilator data that the patient's lung has been collapsed, for example. The surgical hub **106**, **206** can infer that the operative portion of the procedure has commenced as it can compare the detection of the patient's lung collapsing to the expected steps of the procedure (which can be accessed or retrieved previously) and thereby determine that collapsing the lung is the first operative step in this particular procedure.

Eighth step **S216**, the medical imaging device (e.g., a scope) is inserted and video from the medical imaging device is initiated. The surgical hub **106**, **206** receives the medical imaging device data (i.e., video or image data) through its connection to the medical imaging device. Upon receipt of the medical imaging device data, the surgical hub **106**, **206** can determine that the laparoscopic portion of the surgical procedure has commenced. Further, the surgical hub **106**, **206** can determine that the particular procedure being performed is a segmentectomy, as opposed to a lobectomy (note that a wedge procedure has already been discounted by the surgical hub **106**, **206** based on data received at the second step **S204** of the procedure). The data from the medical imaging device **124** (FIG. **2**) can be utilized to determine contextual information regarding the type of procedure being performed in a number of different ways, including by determining the angle at which the medical imaging device is oriented with respect to the visualization of the patient's anatomy, monitoring the number or medical imaging devices being utilized (i.e., that are activated and paired with the surgical hub **106**, **206**), and monitoring the types of visualization devices utilized. For example, one technique for performing a VATS lobectomy places the camera in the lower anterior corner of the patient's chest cavity above the diaphragm, whereas one technique for performing a VATS segmentectomy places the camera in an anterior intercostal position relative to the segmental fissure. Using pattern recognition or machine learning techniques, for example, the situational awareness system can be trained to recognize the positioning of the medical imaging device according to the visualization of the patient's anatomy. As another example, one technique for performing a VATS lobectomy utilizes a single medical imaging device, whereas another technique for performing a VATS segmentectomy utilizes multiple cameras. As yet another example, one technique for performing a VATS segmentectomy utilizes an infrared light source (which can be communicably coupled to the surgical hub as part of the visualization system) to visualize the segmental fissure, which is not utilized in a VATS lobectomy. By tracking any or all of this data from the medical imaging device, the surgical hub **106**, **206** can thereby determine the specific type of surgical procedure being performed and/or the technique being used for a particular type of surgical procedure.

Ninth step **S218**, the surgical team begins the dissection step of the procedure. The surgical hub **106**, **206** can infer that the surgeon is in the process of dissecting to mobilize the patient's lung because it receives data from the RF or ultrasonic generator indicating that an energy instrument is being fired. The surgical hub **106**, **206** can cross-reference the received data with the retrieved steps of the surgical procedure to determine that an energy instrument being fired at this point in the process (i.e., after the completion of the previously discussed steps of the procedure) corresponds to the dissection step. In certain instances, the energy instrument can be an energy tool mounted to a robotic arm of a robotic surgical system.

Tenth step **S220**, the surgical team proceeds to the ligation step of the procedure. The surgical hub **106**, **206** can infer that the surgeon is ligating arteries and veins because it receives data from the surgical stapling and cutting instrument indicating that the instrument is being fired. Similarly to the prior step, the surgical hub **106**, **206** can derive this inference by cross-referencing the receipt of data from the surgical stapling and cutting instrument with the retrieved steps in the process. In certain instances, the surgical instrument can be a surgical tool mounted to a robotic arm of a robotic surgical system.

Eleventh step **S222**, the segmentectomy portion of the procedure is performed. The surgical hub **106**, **206** can infer that the surgeon is transecting the parenchyma based on data from the surgical stapling and cutting instrument, including data from its cartridge. The cartridge data can correspond to the size or type of staple being fired by the instrument, for example. As different types of staples are utilized for different types of tissues, the cartridge data can thus indicate the type of tissue being stapled and/or transected. In this case, the type of staple being fired is utilized for parenchyma (or other similar tissue types), which allows the surgical hub **106**, **206** to infer that the segmentectomy portion of the procedure is being performed.

Twelfth step **S224**, the node dissection step is then performed. The surgical hub **106**, **206** can infer that the surgical team is dissecting the node and performing a leak test based on data received from the generator indicating that an RF or ultrasonic instrument is being fired. For this particular procedure, an RF or ultrasonic instrument being utilized after parenchyma was transected corresponds to the node dissection step, which allows the surgical hub **106**, **206** to make this inference. It should be noted that surgeons regularly switch back and forth between surgical stapling/cutting instruments and surgical energy (i.e., RF or ultrasonic) instruments depending upon the particular step in the procedure because different instruments are better adapted for particular tasks. Therefore, the particular sequence in which the stapling/cutting instruments and surgical energy instruments are used can indicate what step of the procedure the surgeon is performing. Moreover, in certain instances, robotic tools can be utilized for one or more steps in a surgical procedure and/or handheld surgical instruments can be utilized for one or more steps in the surgical procedure. The surgeon(s) can alternate between robotic tools and handheld surgical instruments and/or can use the devices concurrently, for example. Upon completion of the twelfth

step S224, the incisions are closed up and the post-operative portion of the procedure begins.

Thirteenth step S226, the patient's anesthesia is reversed. The surgical hub **106**, **206** can infer that the patient is emerging from the anesthesia based on the ventilator data (i.e., the patient's breathing rate begins increasing), for example.

Lastly, the fourteenth step S228 is that the medical personnel remove the various patient monitoring devices from the patient. The surgical hub **106**, **206** can thus infer that the patient is being transferred to a recovery room when the hub loses EKG, BP, and other data from the patient monitoring devices. As can be seen from the description of this illustrative procedure, the surgical hub **106**, **206** can determine or infer when each step of a given surgical procedure is taking place according to data received from the various data sources that are communicably coupled to the surgical hub **106**, **206**.

Situational awareness is further described in U.S. Provisional Patent Application Ser. No. 62/611,341, titled INTERACTIVE SURGICAL PLATFORM, filed Dec. 28, 2017, which is incorporated by reference herein in its entirety. In certain instances, operation of a robotic surgical system, including the various robotic surgical systems disclosed herein, for example, can be controlled by the hub **106**, **206** based on its situational awareness and/or feedback from the components thereof and/or based on information from the cloud **104**.

## EXAMPLES

Various aspects of the subject matter described herein are set out in the following numbered examples.

Example 1: A method implemented by a surgical instrument comprising first and second jaws and a flexible circuit comprising multiple sensors to optimize performance of a radio frequency (RF) device, the flexible circuit comprising at least one therapeutic electrode couplable to a source of RF energy, at least two sensing electrodes, and at least one insulative layer, the insulative layer is positioned between the at least one therapeutic electrode and the at least two sensing electrodes, the method comprising: contacting tissue positioned between the first and second jaws of the surgical instrument with the at least one therapeutic electrode and at the least two sensing electrodes; sensing signals from the at the least two sensing electrodes; and controlling RF energy delivered to the at least one therapeutic electrode based on the sensed signals.

Example 2: The method of Example 1, further comprising sensing, by the at least two sensing electrodes, impedance of the tissue positioned between the first and second jaws of the surgical instrument; electrical continuity of the tissue; or a temperature transition point in the tissue; or a combination thereof.

Example 3: The method of any one of Examples 1-2, further comprising, sensing, by the at least two sensing electrodes, a parameter associated with tissue positioned between first and second jaws of the surgical instrument.

Example 4: The method of Example 4, further comprising, adaptively controlling the RF energy delivered to the at least one therapeutic electrode based on the parameter sensed by the at least two sensing electrodes.

Example 5: A method implemented by a surgical instrument comprising an end effector, a marking assembly, and a control circuit, the end effector comprising a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, a plurality of sensors, and a tissue-treatment mechanism configured to apply a tissue treatment to tissue grasped between the first jaw and the second jaw, the method comprising: receiving, by the control circuit, a plurality of sensor signals from the plurality of sensors indicative of application of a tissue treatment to the tissue; controlling, by the control circuit, radiofrequency (RF) energy to the end effector to treat the tissue; applying, by the marking assembly, a distinct marking to the tissue unique to the tissue treatment application, wherein the distinct marking distinguishes the tissue treatment application from other tissue treatment applications.

Example 6: The method of Example 5, wherein the end effector includes a cutting member configured to transect tissue, the method further comprising creating the distinct marking, by the marking assembly, adjacent a transection line defined in the tissue by the cutting member.

Example 7: The method of any one of Examples 5-6, further comprising, sensing, by the plurality of sensors, a parameter associated with tissue positioned between first and second jaws of the surgical instrument.

Example 8: The method of Example 7, further comprising, adaptively controlling the RF energy delivered to the at least one therapeutic electrode based on the parameter sensed by the plurality of sensors.

Example 9. A method implemented by a surgical instrument comprising a control circuit, a multi-level flexible electrode, the multi-level flexible electrode comprises first, second, and third insulative layers, the multi-level flexible electrode further comprises at least one therapeutic electrode and at least two sensing electrodes, the therapeutic electrode is positioned between the first and second insulative layers, wherein the therapeutic electrode is couplable to a source of radiofrequency (RF) energy, the sensing electrode is positioned between the second and third insulative layers, the method comprising: contacting tissue by the at least one therapeutic electrode and the at least two sensing electrodes; delivering RF energy to the contacted tissue by the at least one therapeutic electrode; sensing, by the at least two sensing electrodes, a parameter associated with tissue positioned between first and second jaws of the surgical instrument; and controlling, by the control circuit, RF energy delivered to the at least one therapeutic electrode based on the sensed parameter.

Example 10: The method of Example 9, further comprising sensing, by the at least two sensing electrodes, impedance of the tissue positioned between the first and second jaws of the surgical instrument; electrical continuity of the tissue; or a temperature transition point in the tissue; or a combination thereof.

Example 11: The method of any one of Examples 9-10, further comprising: applying a tissue treatment, by the at least one therapeutic electrode, to tissue grasped between the first jaw and the second jaw; receiving, by control circuit, sensor signals indicative of application of the tissue treatment to the tissue; and applying, by a marking assembly, a distinct marking to the tissue unique to the tissue treatment application; wherein the distinct marking distinguishes the tissue treatment application from other tissue treatment applications.

Various additional aspects of the subject matter described herein are set out in the following numbered examples.

Example 1: A flexible electrode of a surgical instrument is disclosed. The flexible electrode comprises a therapeutic electrode couplable to a source of radiofrequency energy, a sensing electrode, and an insulative layer. The insulative layer is positioned between the therapeutic electrode and the sensing electrode. The therapeutic electrode and the sensing

electrode are configured to contact tissue positioned between first and second jaws of the surgical instrument.

Example 2: The flexible electrode of Example 1, wherein the therapeutic electrode comprises a rectangular shape.

Example 3: The flexible electrode of any one of Examples 1 and 2, wherein the sensing electrode overlays the therapeutic electrode.

Example 4: The flexible electrode of any one of Examples 1-3, wherein the sensing electrode comprises a patterned shape comprising a rectangular portion and multiple fingers extending from the rectangular portion.

Example 5: The flexible electrode of any one of Examples 1-4, wherein the sensing electrode is configured to help determine at least one of the following: an impedance of the tissue positioned between the first and second jaws of the surgical instrument; an electrical continuity of the tissue; and a temperature transition point in the tissue.

Example 6: The flexible electrode of any one of Examples 1, 2, 4, and 5, wherein the insulative layer overlays the therapeutic sensing electrode.

Example 7: The flexible electrode of any one of Examples 1-6, wherein the insulative layer comprises a rectangular portion and multiple fingers extending from the rectangular portion.

Example 8: The flexible electrode of any one of Examples 1-7, wherein the insulative layer is congruent with the sensing electrode.

Example 9: The flexible electrode of any one of Examples 1-8, wherein a flexibility of the insulative layer is greater than a flexibility of the therapeutic electrode and a flexibility of the sensing electrode.

Example 10: The flexible electrode of any one of Examples 1-9, further comprising a second insulative layer, wherein the therapeutic layer is positioned between the insulative layer and the second instulative layer.

Example 11: The flexible electrode of Example 10, further comprising a third insulative layer, wherein the sensing electrode is positioned between the insulative layer and the third insulative layer.

Example 12: A flexible electrode assembly of a surgical instrument is disclosed. The flexible electrode assembly comprises first and second therapeutic electrodes couplable to a source of radiofrequency energy and first and second sensing electrodes configured to help determine a parameter associated with tissue positioned between first and second jaws of the surgical instrument. The flexible electrode assembly further comprises a first insulative layer positioned between the first therapeutic electrode and the first sensing electrode and a second insulative layer positioned between the second therapeutic electrode and the second sensing electrode, wherein the first and second therapeutic electrodes and the first and second sensing electrodes are configured to contact the tissue.

Example 13: The flexible electrode assembly of Example 12, wherein the first therapeutic electrode, the first sensing electrode and the first insulative layer are positioned on a first side of a knife slot of the surgical instrument, and the second therapeutic electrode, the second sensing electrode and the first insulative layer are positioned on an opposite side of the knife slot.

Example 14: The flexible electrode assembly of any one of Examples 12 and 13, wherein the first and second sensing electrodes are configured to help determine at least one of the following: an impedance of the tissue positioned between the first and second jaws of the surgical instrument; an electrical continuity of the tissue; and a temperature transition point in the tissue.

Example 15: The flexible electrode assembly of any one of Examples 12-14, wherein each of the first and second sensing electrodes comprise a patterned shape comprising a rectangular portion and multiple fingers extending from the rectangular portion.

Example 16: The flexible electrode assembly of any one of Examples 12-15, wherein each of the first and second insulative layers comprise a patterned shape comprising a rectangular portion and multiple fingers extending from the rectangular portion.

Example 17: The flexible electrode assembly of any one of Examples 12-16, wherein a flexibility of the first and second insulative layers is greater than a flexibility of the first and second therapeutic electrodes and a flexibility of the first and second sensing electrodes.

Example 18: The flexible electrode assembly of any one of Examples 12-17, wherein the first and second sensing electrodes form a conductive gap spacer configured to control a minimum gap between the first and second jaws.

Example 19: A multi-level flexible electrode of a surgical instrument is disclosed. The multi-level flexible electrode comprises first, second, and third insulative layers. The multi-level flexible electrode further comprises a therapeutic electrode and a sensing electrode. The therapeutic electrode is positioned between the first and second insulative layers, wherein the therapeutic electrode is couplable to a source of radiofrequency energy. The sensing electrode is positioned between the second and third insulative layers, wherein the sensing electrode is configured to help determine a parameter associated with tissue positioned between first and second jaws of the surgical instrument, and wherein the therapeutic electrode and the sensing electrode are configured to contact the tissue.

Example 20: The multi-level electrode of Example 19, wherein the sensing electrode is configured to help determine at least one of the following: an impedance of the tissue positioned between the first and second jaws of the surgical instrument; an electrical continuity of the tissue; and a temperature transition point in the tissue.

Various additional aspects of the subject matter described herein are set out in the following numbered examples.

Example 1: A flexible circuit of a surgical instrument is disclosed. The flexible circuit comprises a rigid section and a flexible section. The rigid section comprises interlocking features for mechanical engagement with a component of the surgical instrument. The rigid section has at least one of the following mounted thereon: a processing device; and a logic element. The flexible section is aligned with one of the following: an active bending portion of a shaft assembly of the surgical instrument; and an articulation joint of the shaft assembly.

Example 2: The flexible circuit of Example 1, wherein the flexible section is configured to bend transverse to a longitudinal axis of the shaft assembly.

Example 3: The flexible circuit of any one of Example 1 and 2, wherein the component comprises a channel retainer, and wherein the channel retainer comprises a recess configured to receive the rigid section.

Example 4: The flexible circuit of any one of Examples 1-3, further comprising a conductive trace.

Example 5: The flexible circuit of Example 4, wherein a height of the conductive trace varies along a length of the conductive trace.

Example 6: The flexible circuit of any one of Examples 4 and 5, wherein a width of the conductive trace varies along a length of the conductive trace.

Example 7: The flexible circuit of any one of Examples 4-6, wherein the conductive trace varies in height along a length of the conductive trace and varies in width along the length of the conductive trace.

Example 8: The flexible circuit of any one of Examples 4-7, wherein a height of a first portion of the conductive trace positioned on the flexible section is less than a height of second portion of the conductive trace positioned on the rigid section.

Example 9: The flexible circuit of any one of Examples 4-8, wherein a width of a first portion of the conductive trace positioned on the flexible section is less than a width of second portion of the conductive trace positioned on the rigid section.

Example 10: The flexible circuit of any one of Examples 4-9, wherein a height of a first portion of the conductive trace positioned on the flexible section is less than a height of a second portion of the conductive trace positioned on the rigid section, and a width of the first portion of the conductive trace is greater than a width of the second portion of the conductive trace.

Example 11: The flexible circuit of any one of Examples 1-10, wherein the flexible circuit comprises a strain relief section.

Example 12: The flexible circuit of any one of Examples 1-11, further comprising a conductive pad.

Example 13: The flexible circuit of any one of Examples 1-12, further comprising an electromagnetic shield.

Example 14: A flexible circuit of a surgical instrument is disclosed. The flexible circuit comprises a rigid section, a flexible section, and a conductive trace positioned on both the rigid section and the flexible section. The rigid section has at least one of the following mounted thereon: a processing device; and a logic element. The flexible section is aligned with one of the following: an active bending portion of a shaft assembly of the surgical instrument and an articulation joint of the shaft assembly. A height and a width of the conductive trace varies along a length of the surgical instrument.

Example 15: The flexible circuit of Example 14, wherein the rigid section is configured to mechanically interlock with a component of the surgical instrument.

Example 16: The flexible circuit of Example 15, wherein the component comprises a channel retainer, and wherein the channel retainer comprises a recess configured to receive the rigid section.

Example 17: The flexible circuit of any one of Examples 14-16, wherein the flexible section is configured to bend transverse to a longitudinal axis of the shaft assembly.

Example 18: The flexible circuit of any one of Examples 14-17, wherein a height of a first portion of the conductive trace positioned on the flexible section is less than a height of a second portion of the conductive trace positioned on the rigid section, and a width of the first portion of the conductive trace is greater than a width of the second portion of the conductive trace.

Example 19: A flexible circuit of a surgical instrument is disclosed. The flexible circuit comprises a rigid section, a flexible section, a conductive trace, and an electromagnetic shield. The flexible section is aligned with one of the following: an active bending portion of a shaft assembly of the surgical instrument; and an articulation joint of the shaft assembly. The conductive trace is positioned on both the rigid section and the flexible section, wherein a height and a width of the conductive trace varies along a length of the surgical instrument.

Example 20: The flexible circuit of Example 19, wherein a height of a first portion of the conductive trace positioned on the flexible section is less than a height of a second portion of the conductive trace positioned on the rigid section, and a width of the first portion of the conductive trace is greater than a width of the second portion of the conductive trace.

Various additional aspects of the subject matter described herein are set out in the following numbered examples.

Example 1: A surgical instrument is disclosed. The surgical instrument comprises an end effector and a marking assembly. The end effector comprises a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, and a tissue-treatment mechanism configured to apply a tissue treatment to tissue grasped between the first jaw and the second jaw. The marking assembly is configured to apply a distinct marking to the tissue unique to each tissue treatment application. The distinct marking distinguishes the tissue treatment application from other tissue treatment applications.

Example 2: The surgical instrument of Example 1, wherein the end effector includes a cutting member configured to transect tissue, and wherein the marking assembly is configured to create the distinct marking adjacent a transection line defined in the tissue by the cutting member.

Example 3: The surgical instrument of any one of Examples 1 and 2, wherein the distinct marking is visible only in the presence of a light source outside of the visible spectrum.

Example 4: The surgical instrument of any one of Examples 1-3, wherein the distinct marking is configured to fluoresce under an applied light source outside of the visible spectrum.

Example 5: The surgical instrument of any one of Examples 1-4, wherein the distinct marking is detectable through stimulation by at least one of a light source, a radiation source, and an illumination source.

Example 6: The surgical instrument of any one of Examples 1-5, wherein the tissue treatment mechanism comprises a staple cartridge configured to deploy staples into the tissue in the tissue treatment application.

Example 7: The surgical instrument of any one of Examples 1-6, wherein the tissue treatment mechanism comprises an electrode configured to deliver therapeutic energy to the tissue in the tissue treatment application.

Example 8: The surgical instrument of any one of Examples 1-7, wherein the tissue treatment mechanism comprises a transection member movable to transect the tissue in the tissue treatment application.

Example 9: The surgical instrument of any one of Examples 1-8, wherein application of the tissue treatment by the tissue-treatment mechanisms triggers application of the distinct marking to the tissue by the marking assembly.

Example 10: The surgical instrument of any one of Examples 1-9, wherein the marking assembly comprises a plurality of spaced apart applicators.

Example 11: The surgical instrument of Example 10, wherein the plurality of applicators comprises a proximal applicator and a distal applicator.

Example 12: The surgical instrument of any one of Examples 10 and 11, wherein the end effector comprises a longitudinal slot, and wherein the first applicator on a first side of the longitudinal slot and a second applicator on a second side of the longitudinal slot opposite the first side.

Example 13: A surgical instrument is disclosed. The surgical instrument comprises an end effector, a marking assembly, and a control circuit. The end effector comprises

a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, and a tissue-treatment mechanism configured to apply a tissue treatment to tissue grasped between the first jaw and the second jaw. The control circuit is configured to receive sensor signals indicative of application of a tissue treatment to the tissue and cause the marking assembly to apply a distinct marking to the tissue unique to the tissue treatment application, wherein the distinct marking distinguishes the tissue treatment application from other tissue treatment applications.

Example 14: The surgical instrument of Example 13, wherein the end effector includes a cutting member configured to transect tissue, and wherein the marking assembly is configured to create the distinct marking adjacent a transection line defined in the tissue by the cutting member.

Example 15: The surgical instrument of any one of Examples 13 and 14, wherein the distinct marking is visible only in the presence of a light source outside of the visible spectrum.

Example 16: The surgical instrument of any one of Examples 13-15, wherein the distinct marking is configured to fluoresce under an applied light source outside of the visible spectrum.

Example 17: The surgical instrument of any one of Examples 13-16, wherein the distinct marking is detectable through stimulation by at least one of a light source, a radiation source, and an illumination source.

Example 18: The surgical instrument of any one of Examples 13-17, wherein application of the tissue treatment by the tissue-treatment mechanisms triggers application of the distinct marking to the tissue by the marking assembly.

Example 19: The surgical instrument of any one of Examples 13-18, wherein the marking assembly comprises a plurality of spaced apart applicators.

Example 20: A surgical instrument is disclosed. The surgical instrument comprises an end effector comprising a first jaw, a second jaw movable relative to the first jaw to grasp tissue therebetween, and a tissue-treatment mechanism configured to apply a tissue treatment to tissue grasped between the first jaw and the second jaw. The surgical instrument further comprises a means for applying a distinct marking to the tissue unique to each tissue treatment application, wherein the distinct marking distinguishes the tissue treatment application from other tissue treatment applications.

Various additional aspects of the subject matter described herein are set out in the following numbered examples.

Example 1: A surgical system for use in a surgical procedure is disclosed. The surgical system comprises a surgical hub, a powered surgical instrument, and a communication module. The communication module is configured to receive first data regarding a first surgical activity of the surgical procedure, receive second data regarding a second surgical activity of the surgical procedure, select transmission rates for transmission of the first data and the second data between the powered surgical instrument and the surgical hub based on at least one characteristic of at least one of the first surgical activity and the second surgical activity, and transmit the first data and the second data between the powered surgical instrument and the surgical hub at the selected transmission rates.

Example 2: The surgical system of Example 1, wherein the surgical instrument comprises an end effector transitionable between an open configuration and a closed configuration to grasp tissue.

Example 3: The surgical system of Example 2, wherein the first data represent force to transition the end effector to the closed configuration over time.

Example 4: The surgical system of any one of Examples 2 and 3, wherein the surgical instrument comprises a translatable member to deploy staples into the tissue grasped by the end effector.

Example 5: The surgical system of Example 4, wherein the second data represent force to move the translatable member over time.

Example 6: The surgical system of any one of Examples 1-5, wherein the first data and the second data are transmitted through a communication channel established between the powered surgical instrument and the surgical hub.

Example 7: The surgical system of Example 6, wherein the communication module is further configured to adjust the transmission rate of at least one of the first data and the second data in response to a change in bandwidth of the communication channel.

Example 8: A surgical system for use in a surgical procedure is disclosed. The surgical system comprises a surgical hub, a powered surgical instrument, and a communication module. The communication module is configured to receive first data regarding a first surgical activity of the surgical procedure, receive second data regarding a second surgical activity of the surgical procedure, and adjust transmission rates for transmission of the first data and the second data between the powered surgical instrument and the surgical hub based on at least one characteristic of at least one of the first surgical activity and the second surgical activity.

Example 9: The surgical system of Example 8, wherein the surgical instrument comprises an end effector transitionable between an open configuration and a closed configuration to grasp tissue.

Example 10: The surgical system of Example 9, wherein the first data represent force to transition the end effector to the closed configuration over time.

Example 11: The surgical system of any one of Examples 9 and 10, wherein the surgical instrument comprises a translatable member movable to deploy staples into the tissue grasped by the end effector.

Example 12: The surgical system of Example 11, wherein the second data represent force to move the translatable member over time.

Example 13: The surgical system of Example 12, wherein the first data and the second data are transmitted through a communication channel established between the powered surgical instrument and the surgical hub.

Example 14: The surgical system of Example 13, wherein the communication module is further configured to adjust the transmission rate of at least one of the first data and the second data in response to a change in bandwidth of the communication channel.

Example 15: A surgical system for use in a surgical procedure is disclosed. The surgical system comprises a surgical hub, a powered surgical instrument, and a communication module. The communication module is configured to receive first data regarding a first surgical activity of the surgical procedure, receive second data regarding a second surgical activity of the surgical procedure, transmit first data and second data between the powered surgical instrument and the surgical hub, detect an irregularity in the second data, and adjust transmission rates of the first data and the second data to prioritize transmission of the irregularity in the second data.

Example 16: The surgical system of Example 15, wherein the surgical instrument comprises an end effector transitionable between an open configuration and a closed configuration to grasp tissue.

Example 17: The surgical system of Example 16, wherein the first data represent force to transition the end effector to the closed configuration over time.

Example 18: The surgical system of any one of Examples 16 and 17, wherein the surgical instrument comprises a translatable member movable to deploy staples into the tissue grasped by the end effector.

Example 19: The surgical system of Example 18, wherein the second data represent force to move the translatable member over time.

Example 20: The surgical system of any one of Examples 12-19, wherein the irregularity in the second data comprises exceeding a predetermined threshold.

While several forms have been illustrated and described, it is not the intention of the applicant to restrict or limit the scope of the appended claims to such detail. Numerous modifications, variations, changes, substitutions, combinations, and equivalents to those forms may be implemented and will occur to those skilled in the art without departing from the scope of the present disclosure. Moreover, the structure of each element associated with the described forms can be alternatively described as a means for providing the function performed by the element. Also, where materials are disclosed for certain components, other materials may be used. It is therefore to be understood that the foregoing description and the appended claims are intended to cover all such modifications, combinations, and variations as falling within the scope of the disclosed forms. The appended claims are intended to cover all such modifications, variations, changes, substitutions, modifications, and equivalents.

The foregoing detailed description has set forth various forms of the devices and/or processes via the use of block diagrams, flowcharts, and/or examples. Insofar as such block diagrams, flowcharts, and/or examples contain one or more functions and/or operations, it will be understood by those within the art that each function and/or operation within such block diagrams, flowcharts, and/or examples can be implemented, individually, and/or collectively, by a wide range of hardware, software, firmware, or virtually any combination thereof. Those skilled in the art will recognize that some aspects of the forms disclosed herein, in whole or in part, can be equivalently implemented in integrated circuits, as one or more computer programs running on one or more computers (e.g., as one or more programs running on one or more computer systems), as one or more programs running on one or more processors (e.g., as one or more programs running on one or more microprocessors), as firmware, or as virtually any combination thereof, and that designing the circuitry and/or writing the code for the software and or firmware would be well within the skill of one of skill in the art in light of this disclosure. In addition, those skilled in the art will appreciate that the mechanisms of the subject matter described herein are capable of being distributed as one or more program products in a variety of forms, and that an illustrative form of the subject matter described herein applies regardless of the particular type of signal bearing medium used to actually carry out the distribution.

Instructions used to program logic to perform various disclosed aspects can be stored within a memory in the system, such as DRAM, cache, flash memory, or other storage. Furthermore, the instructions can be distributed via a network or by way of other computer readable media. Thus a machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer), but is not limited to, floppy diskettes, optical disks, CD-ROMs, and magneto-optical disks, ROMs, RAM, EPROM, EEPROM, magnetic or optical cards, flash memory, or a tangible, machine-readable storage used in the transmission of information over the Internet via electrical, optical, acoustical, or other forms of propagated signals (e.g., carrier waves, IR signals, digital signals, etc.). Accordingly, the non-transitory computer-readable medium includes any type of tangible machine-readable medium suitable for storing or transmitting electronic instructions or information in a form readable by a machine (e.g., a computer).

As used throughout this description, the term "wireless" and its derivatives may be used to describe circuits, devices, systems, methods, techniques, communications channels, etc., that may communicate data through the use of modulated electromagnetic radiation through a non-solid medium. The term does not imply that the associated devices do not contain any wires, although in some aspects they might not. The communication module may implement any of a number of wireless or wired communication standards or protocols, including but not limited to Wi-Fi (IEEE 802.11 family), WiMAX (IEEE 802.16 family), IEEE 802.20, LTE, Ev-DO, HSPA+, HSDPA+, HSUPA+, EDGE, GSM, GPRS, CDMA, TDMA, DECT, Bluetooth, Ethernet derivatives thereof, as well as any other wireless and wired protocols that are designated as 3G, 4G, 5G, and beyond. The computing module may include a plurality of communication modules. For instance, a first communication module may be dedicated to shorter-range wireless communications such as Wi-Fi and Bluetooth, and a second communication module may be dedicated to longer range wireless communications such as GPS, EDGE, GPRS, CDMA, WiMAX, LTE, Ev-DO, and others.

As used in any aspect herein, the term "control circuit" may refer to, for example, hardwired circuitry, programmable circuitry (e.g., a computer processor comprising one or more individual instruction processing cores, processing unit, processor, microcontroller, microcontroller unit, controller, DSP, PLD, programmable logic array (PLA), or FPGA), state machine circuitry, firmware that stores instructions executed by programmable circuitry, and any combination thereof. The control circuit may, collectively or individually, be embodied as circuitry that forms part of a larger system, for example, an integrated circuit (IC), an application-specific integrated circuit (ASIC), a system on-chip (SoC), desktop computers, laptop computers, tablet computers, servers, smart phones, etc. Accordingly, as used herein "control circuit" includes, but is not limited to, electrical circuitry having at least one discrete electrical circuit, electrical circuitry having at least one integrated circuit, electrical circuitry having at least one application specific integrated circuit, electrical circuitry forming a general purpose computing device configured by a computer program (e.g., a general purpose computer configured by a computer program which at least partially carries out processes and/or devices described herein, or a microprocessor configured by a computer program which at least partially carries out processes and/or devices described herein), electrical circuitry forming a memory device (e.g., forms of random access memory), and/or electrical circuitry forming a communications device (e.g., a modem, communications switch, or optical-electrical equipment). Those having skill in the art will recognize that the subject matter described

herein may be implemented in an analog or digital fashion or some combination thereof.

As used herein a processor or processing unit is an electronic circuit which performs operations on some external data source, usually memory or some other data stream. The term is used herein to refer to the central processor (central processing unit) in a system or computer systems (especially SoCs) that combine a number of specialized "processors."

As used herein, an SoC or system on chip (SOC) is an IC that integrates all components of a computer or other electronic systems. It may contain digital, analog, mixed-signal, and often radio-frequency functions-all on a single substrate. A SoC integrates a microcontroller (or microprocessor) with advanced peripherals like graphics processing unit (GPU), Wi-Fi module, or coprocessor. A SoC may or may not contain built-in memory.

As used herein, a microcontroller or controller is a system that integrates a microprocessor with peripheral circuits and memory. A microcontroller (or MCU for microcontroller unit) may be implemented as a small computer on a single integrated circuit. It may be similar to a SoC; an SoC may include a microcontroller as one of its components. A microcontroller may contain one or more core processing units (CPUs) along with memory and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash or OTP ROM is also often included on chip, as well as a small amount of RAM. Microcontrollers may be employed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips.

As used herein, the term controller or microcontroller may be a stand-alone IC or chip device that interfaces with a peripheral device. This may be a link between two parts of a computer or a controller on an external device that manages the operation of (and connection with) that device.

Any of the processors or microcontrollers described herein, may be implemented by any single core or multicore processor such as those known under the trade name ARM Cortex by Texas Instruments. In one aspect, the processor may be an LM4F230H5QR ARM Cortex-M4F Processor Core, available from Texas Instruments, for example, comprising on-chip memory of 256 KB single-cycle flash memory, or other NVM, up to 40 MHz, a prefetch buffer to improve performance above 40 MHz, a 32 KB single-cycle SRAM, internal ROM loaded with StellarisWare® software, 2 KB electrically EEPROM, one or more PWM modules, one or more QEI analog, or one or more 12-bit ADCs with 12 analog input channels, details of which are available for the product datasheet.

In one aspect, the processor may comprise a safety controller comprising two controller-based families such as TMS570 and RM4x known under the trade name Hercules ARM Cortex R4, also by Texas Instruments. The safety controller may be configured specifically for IEC 61508 and ISO 26262 safety critical applications, among others, to provide advanced integrated safety features while delivering scalable performance, connectivity, and memory options.

As used in any aspect herein, the term "logic" may refer to an app, software, firmware, and/or circuitry configured to perform any of the aforementioned operations. Software may be embodied as a software package, code, instructions, instruction sets, and/or data recorded on non-transitory computer readable storage medium. Firmware may be embodied as code, instructions, or instruction sets and/or data that are hard-coded (e.g., non-volatile) in memory devices.

As used in any aspect herein, the terms "component," "system," "module," and the like can refer to a computer-related entity, either hardware, a combination of hardware and software, software, or software in execution.

As used in any aspect herein, an "algorithm" refers to a self-consistent sequence of steps leading to a desired result, where a "step" refers to a manipulation of physical quantities, and/or logic states, which may, though need not necessarily, take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It is common usage to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. These and similar terms may be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities and/or states.

A network may include a packet switched network. The communication devices may be capable of communicating with each other using a selected packet switched network communications protocol. One example communications protocol may include an Ethernet communications protocol that may be capable permitting communication using a Transmission Control Protocol/Internet Protocol (TCP/IP). The Ethernet protocol may comply or be compatible with the Ethernet standard published by the Institute of Electrical and Electronics Engineers (IEEE) titled "IEEE 802.3 Standard," published in December 2008 and/or later versions of this standard. Alternatively or additionally, the communication devices may be capable of communicating with each other using an X.25 communications protocol. The X.25 communications protocol may comply or be compatible with a standard promulgated by the International Telecommunication Union-Telecommunication Standardization Sector (ITU-T). Alternatively or additionally, the communication devices may be capable of communicating with each other using a frame relay communications protocol. The frame relay communications protocol may comply or be compatible with a standard promulgated by Consultative Committee for International Telegraph and Telephone (CCITT) and/or the American National Standards Institute (ANSI). Alternatively or additionally, the transceivers may be capable of communicating with each other using an Asynchronous Transfer Mode (ATM) communications protocol. The ATM communications protocol may comply or be compatible with an ATM standard published by the ATM Forum titled "ATM-MPLS Network Interworking 2.0" published August 2001, and/or later versions of this standard. Of course, different and/or after-developed connection-oriented network communication protocols are equally contemplated herein.

Unless specifically stated otherwise as apparent from the foregoing disclosure, it is appreciated that, throughout the foregoing disclosure, discussions using terms such as "processing," "computing," "calculating," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

One or more components may be referred to herein as "configured to," "configurable to," "operable/operative to," "adapted/adaptable," "able to," "conformable/conformed to," etc. Those skilled in the art will recognize that "configured to" can generally encompass active-state compo-

nents and/or inactive-state components and/or standby-state components, unless context requires otherwise.

The terms "proximal" and "distal" are used herein with reference to a clinician manipulating the handle portion of the surgical instrument. The term "proximal" refers to the portion closest to the clinician, and the term "distal" refers to the portion located away from the clinician. It will be further appreciated that, for convenience and clarity, spatial terms such as "vertical," "horizontal," "up," "down," "left," and "right" may be used herein with respect to the drawings. However, surgical instruments are used in many orientations and positions, and these terms are not intended to be limiting and/or absolute.

Modular devices include the modules (as described in connection with FIGS. **3** and **9**, for example) that are receivable within a surgical hub and the surgical devices or instruments that can be connected to the various modules in order to connect or pair with the corresponding surgical hub. The modular devices include, for example, intelligent surgical instruments, medical imaging devices, suction/irrigation devices, smoke evacuators, energy generators, ventilators, insufflators, and displays. The modular devices described herein can be controlled by control algorithms. The control algorithms can be executed on the modular device itself, on the surgical hub to which the particular modular device is paired, or on both the modular device and the surgical hub (e.g., via a distributed computing architecture). In some exemplifications, the modular devices' control algorithms control the devices based on data sensed by the modular device itself (i.e., by sensors in, on, or connected to the modular device). This data can be related to the patient being operated on (e.g., tissue properties or insufflation pressure) or the modular device itself (e.g., the rate at which a knife is being advanced, motor current, or energy levels). For example, a control algorithm for a surgical stapling and cutting instrument can control the rate at which the instrument's motor drives its knife through tissue according to resistance encountered by the knife as it advances.

Those skilled in the art will recognize that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to claims containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations.

In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means at least two recitations, or two or more recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that typically a disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms unless context dictates otherwise. For example, the phrase "A or B" will be typically understood to include the possibilities of "A" or "B" or "A and B."

With respect to the appended claims, those skilled in the art will appreciate that recited operations therein may generally be performed in any order. Also, although various operational flow diagrams are presented in a sequence(s), it should be understood that the various operations may be performed in other orders than those which are illustrated, or may be performed concurrently. Examples of such alternate orderings may include overlapping, interleaved, interrupted, reordered, incremental, preparatory, supplemental, simultaneous, reverse, or other variant orderings, unless context dictates otherwise. Furthermore, terms like "responsive to," "related to," or other past-tense adjectives are generally not intended to exclude such variants, unless context dictates otherwise.

It is worthy to note that any reference to "one aspect," "an aspect," "an exemplification," "one exemplification," and the like means that a particular feature, structure, or characteristic described in connection with the aspect is included in at least one aspect. Thus, appearances of the phrases "in one aspect," "in an aspect," "in an exemplification," and "in one exemplification" in various places throughout the specification are not necessarily all referring to the same aspect. Furthermore, the particular features, structures or characteristics may be combined in any suitable manner in one or more aspects.

Any patent application, patent, non-patent publication, or other disclosure material referred to in this specification and/or listed in any Application Data Sheet is incorporated by reference herein, to the extent that the incorporated materials is not inconsistent herewith. As such, and to the extent necessary, the disclosure as explicitly set forth herein supersedes any conflicting material incorporated herein by reference. Any material, or portion thereof, that is said to be incorporated by reference herein, but which conflicts with existing definitions, statements, or other disclosure material set forth herein will only be incorporated to the extent that no conflict arises between that incorporated material and the existing disclosure material.

In summary, numerous benefits have been described which result from employing the concepts described herein.

The foregoing description of the one or more forms has been presented for purposes of illustration and description. It is not intended to be exhaustive or limiting to the precise form disclosed. Modifications or variations are possible in light of the above teachings. The one or more forms were chosen and described in order to illustrate principles and practical application to thereby enable one of ordinary skill in the art to utilize the various forms and with various modifications as are suited to the particular use contemplated. It is intended that the claims submitted herewith define the overall scope.

The invention claimed is:

**1**. A method implemented by a surgical instrument comprising a first jaw, a second jaw, and a flexible electrode positioned on one of the first and second jaws, the flexible electrode including a therapeutic electrode and a sensing electrode positioned over the therapeutic electrode, the sensing electrode including a base and a plurality of fingers that extend laterally from the base, wherein the plurality of fingers cooperate to define openings between pairs of the fingers and wherein a therapeutic portion of the therapeutic electrode is exposed through each opening, the method comprising:

contacting tissue with the therapeutic electrode and the sensing electrode;

delivering, by the therapeutic portions of the therapeutic electrode, an amount of radio frequency (RF) energy to the tissue;

sensing, via the sensing electrode and in response to delivering the RF energy to the tissue, a parameter associated with the tissue.

**2**. The method of claim **1**, wherein sensing the parameter associated with the tissue comprises sensing impedance of the tissue positioned between the first and second jaws of the surgical instrument; electrical continuity of the tissue; a temperature transition point in the tissue; or a combination thereof.

**3**. The method of claim **1**, further comprising, adaptively controlling the RF energy delivered to the at least one therapeutic electrode based on the sensed parameter associated with the tissue.

**4**. The method of claim **1**, wherein the end effector includes a cutting member configured to transect tissue, the method further comprising creating a distinct marking, by a marking assembly of the surgical instrument, adjacent a transection line defined in the tissue by the cutting member, wherein the distinct marking is distinguishes a tissue treatment application from other tissue treatment applications.

**5**. The method of claim **1**, wherein each finger of the plurality of fingers of the sensing electrode is a rectangular-shaped finger, and

wherein delivering the amount of RF energy to the tissue comprises delivering, via the therapeutic portions of the therapeutic electrode exposed through the openings defined between the pairs of rectangular-shaped fingers, an amount of RF energy to the tissue.

**6**. The method of claim **1**, wherein each finger of the plurality of fingers of the sensing electrode is a triangular-shaped finger, and

wherein delivering the amount of RF energy to the tissue comprises delivering, via the therapeutic portions of the therapeutic electrode exposed through the openings defined between the pairs of triangular-shaped fingers, an amount of RF energy to the tissue.

**7**. The method of claim **1**, wherein the flexible electrode further includes an insulative layer positioned between the therapeutic electrode and the sensing electrode, and

wherein delivering the amount of RF energy to the tissue comprises delivering, by the therapeutic portions of the therapeutic electrode, an amount of radio frequency (RF) energy to the tissue while the sensing electrode is insulated from the therapeutic electrode by the insulative layer.

**8**. The method of claim **1**, further comprising controlling the amount of RF energy delivered to the tissue by the therapeutic electrode based on the parameter associated with the tissue.

**9**. A surgical instrument for use in a surgical procedure, the surgical instrument comprising:

an end effector comprising:

a first jaw,

a second jaw movable from an open position to a closed position, and

a flexible electrode position on either the first jaw or the second jaw, the flexible electrode comprising:

a therapeutic electrode, and

a sensing electrode positioned over the therapeutic electrode and including a base and a plurality of fingers that extend laterally from the base, wherein the plurality of fingers cooperate to define openings between pairs of the fingers and wherein a therapeutic portion of the therapeutic electrode is exposed through each opening; and

a control circuit configured to:

deliver, by the therapeutic portions of the therapeutic electrode, an amount of radio frequency (RF) energy to tissue positioned between the first and second jaws, and

sense, by the sensing electrode and in response to the delivery of the RF energy to the tissue, a parameter associated with tissue positioned between the first and second jaws of the surgical instrument.

**10**. The surgical instrument of claim **9**, wherein the parameters comprises an impedance of the tissue positioned between the first and second jaws of the surgical instrument; an electrical continuity of the tissue; a temperature transition point in the tissue; or a combination thereof.

**11**. The surgical instrument of claim **9**, wherein each finger of the plurality of fingers of the sensing electrode has a rectangular shape.

**12**. The surgical instrument of claim **11**, wherein each therapeutic portion of the therapeutic electrode has a rectangular shape.

**13**. The surgical instrument of claim **12**, wherein each therapeutic portion has a surface area that is greater than a surface area of each finger.

**14**. The surgical instrument of claim **9**, wherein each finger of the plurality of fingers has a triangular shape.

**15**. The surgical instrument of claim **9**, further comprising an insulative layer positioned between the therapeutic electrode and the sensing electrode.

**16**. The surgical instrument of claim **15**, wherein the insulative layer an insulative base and a plurality of insulative fingers that extend laterally from the insulative base.

**17**. The surgical instrument of claim **16**, wherein each insulative finger of the insulative layer has a rectangular shape.

**18**. The surgical instrument of claim **17**, wherein each insulative finger of the insulative layer is aligned with and supports a corresponding finger of the sensing electrode.

**19**. The surgical instrument of claim **18**, wherein each insulative finger of the plurality of insulative fingers has a width that is greater than each finger of the plurality of figures of the sensing electrode.

**20**. The surgical instrument of claim **15**, further comprising another insulative layer positioned under the therapeutic electrode.

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